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THE FUTURE OF OCEAN TECHNOLOGY

2020 EDITION


CABLE TRACKER-1 PROBE

FEATURES

ADVERTISERS INDEX

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THE FUTURE IS **WHAT WE MAKE IT**

ED FREEMAN
Editor, ON&T

Disruptive. That is perhaps one of the more generous adjectives to describe 2020. And while many professionals in the ocean and offshore industries will be quick to toss out this year's dissenting wall planner, we take solace in the fact that widespread disruption triggered a most impassioned and collective response to weathering the proverbial storm.

This is perhaps best manifest in the tide of press activity that we, at ON&T, have reported on throughout the year—a surge of announcements relating to virtual product launches, online conferences, contract awards, and breakthrough research. Not only is this symptomatic of a creative and active marketplace, but also indicative of our sector's outlook for 2021, a year that kicks off a new decade—at least in terms of scientific convention—of ocean exploration. There is, unequivocally, much to look forward to.

Many discoveries will be driven by landmark global initiatives, like the UN's Decade of Ocean Science for Sustainable Development (2021-2030) or The Nippon Foundation-GEBCO Seabed 2030 Project. Some advances will be fueled by emerging commercial opportunities in the offshore energy market, while others will be born out of necessity, as industries seek to comply with ever tightening environmental regulations.

All of this will be reliant on meaningful action and a cooperative approach from professional bodies and policy makers alike, but progress will also be contingent on the accelerating capacity of ocean technology.

For the editorial team at ON&T, this gave fresh impetus to our 2020 special edition, *The Future of Ocean Technology*. The only thing we are more confident about than the coming decade being one of unprecedented transformation, is the leading role that ocean tech will play in reimagining the way we work at sea. Be it in the name of commercial enterprise, defense and security, or scientific inquiry, our capabilities by 2030 will far outstrip our present-day projections. That is a tantalizing prospect, to say the least.

And, as we chart these new horizons, expert thought leadership becomes imperative to aligning expectations with what's reasonably feasible. Here, in this quest to balance pioneering vision with scalable innovation, we profile some of the leading voices and ground-breaking technologies likely to define what's next. From autonomous vehicles to renewable energy solutions, from ROVs to diving technologies, we are delighted to showcase the stellar minds and companies shaping *The Future of Ocean Technology*.

Bring on the disruption.

ON THE HORIZON

January 2021:
The Essential 2021 Offshore Toolkit

Breakthrough technologies transforming the way we work at sea and extend our reach offshore.

Technologies: *ROV tooling & control, Subsea cables, Remote inspection, Supply vessels, Turbines, Tethers, and more.*

Industry Focus: *Offshore Energy & Renewables, Marine Survey, Scientific, Defense*

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THE FUTURE OF OFFSHORE MONITORING & REMOTE OPERATIONS

By João "JP" Ferreira
Co-Founder and Business Development Director, Abyssal

At Abyssal we see the future of ocean technology firmly rooted in developing and implementing cutting-edge software for the offshore industries that promote the ever-improving safety, efficiency, and sustainability of subsea operations. Regardless of the phase of development, Abyssal's products provide the real-time, visual and collaborative tools to give offshore developers a distinct advantage in the planning, maintenance, and execution of complex projects. We work with private entities, industry partners, and academic bodies alike, equipping them with software solutions that prioritize the security and data protection of their key assets.

We recognize that the coming decade will be a transformative one, in which we are likely to see some paradoxical shifts in how we manage offshore activities, and this underlines the importance of a software ecosystem that helps facilitate these necessary shifts. We see the decade ahead as one that seeks to develop sustainable, safer and more efficient approaches to the rigors of subsea intervention and this, unquestionably, will demand the enhancement of remote operations and the ability to integrate autonomous solutions to everyday challenges.

BEST-IN-CLASS ANALYSIS AND MONITORING

Abyssal is first in its class when it comes to visualization, offshore monitoring, and analysis. With extensive experience in remote and hostile subsea environments, we've dedicated ourselves to ensuring that our solutions guarantee the highest returns for the least environmental and financial offsets. We're able to recreate your environments with survey-grade accuracy, use AI to analyze recorded videos and point out problem spots, as well as perform virtual inspections that save you time and money. And a lot of it, too; we're able to improve pilot efficiency by up to 40% and decrease downtime due to visibility issues to an absolute minimum, all the while guaranteeing safety.

PLANNING AND MONITORING FROM ANYWHERE IN THE WORLD

With our proven background in 3D visualization and monitoring, our software suite is tailormade to fit any situation in the subsea industry.

Abyssal Offshore is the complete digital toolkit for your offshore vehicle operations. Allowing you to edit your fields in real time and in 3D. Combined with augmented reality and a state-of-the-art HD video overlay system, it's proven to increase navigation efficiency by up to 40%.

With Abyssal Simulator, you can easily plan, simulate, and train for your missions in survey-grade 3D scenarios. With this tool in hand, you can perform safe accessibility studies, maneuverability studies, and tooling integration testing, while also significantly reducing the duration of live operations and shortening pilot training time by 30%.

Then, you can evaluate your missions collaboratively in Abyssal Cloud—our web solution that combines not just a comprehensive media gallery with mission tracking, but also AI to evaluate mission videos to quickly spot issues, help

» Abyssal software allows users to recreate subsea environments with survey-grade accuracy. (Photo credit: Abyssal)

you plan your next maintenance tasks, and more. Abyssal's software ecosystem ensures that you can plan, anticipate, as well as execute your missions safely and efficiently.

However, monitoring and planning is only part of the picture. The next step is to be able to remotely control vessels of any type during missions with the same level of safety and efficiency—and that's where the future lies for Abyssal.

THE FUTURE IS REMOTE

To allow for the safe and efficient operation of marine autonomous systems, we truly believe that remote operations are key. By lessening the dependence on specialized vessels, the use of marine autonomous systems will significantly reduce the overall operating cost, necessary human exposure, as well as to allow operations to be performed onshore from anywhere in the world.

Additionally, this technology can also significantly increase the profitability of field development in otherwise inaccessible areas. With a shorter response time and a larger operating window, Abyssal's technology can increase production efficiency with the infrastructure already available in your operations.

With our technology, we're able to provide vessel control and dynamic payload software as well as software for remote control of operations, simulation, monitorization, and visualization—all essential to execute your missions while also minimizing your risks.

RISKS, MEET SOLUTIONS

Performing operations remotely is littered with risks. That's why we at Abyssal, with our considerable experience in the field, have painstakingly performed assessments to mitigate those risks. With augmented reality, GIS, AI object recognition, alarms, and anti-collision mechanisms, pilots are able to navigate through low visibility environments like never before.

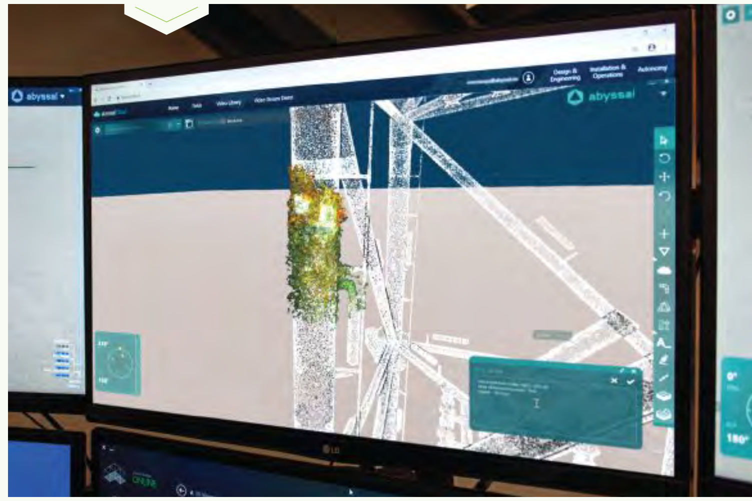
Additionally, foreseeable failures in communication, power, and hardware are backed up by several redundancy measures to ensure that any downtime is minimized. We combat cybersecurity threats by fully adhering to a secure-by-design approach and industry best practices, as well as proactively performing penetration testing of our system.

We are working to bring fully autonomous operations to you, safely, cost-effectively, and in the most environmentally friendly fashion possible. Even the fish love us!

With our technology, not only will you see a reduction in CAPEX and OPEX costs, but we can also curb your daily CO2 emissions by 30 tons. This not only dramatically reduces the environmental impact of your offshore operations but also increases safety at sea by minimizing the necessary manpower deployed.

WITH YOU NO MATTER THE DEPTH

With our proven wealth of experience, our clients feel at ease with the knowledge that they'll be best prepared for remote operations as they can use us in the present to analyze the past and continuously improve the future of operations. Abyssal is dedicated to ensuring that you achieve your mission no matter the depth, in the most safe, secure, and green way imaginable. To learn more, visit www.abyssal.eu



» *Abyssal Cloud ensures that users can plan, anticipate and execute missions safely and efficiently. (Photo credit: Abyssal)*

» *With augmented reality, GIS, AI object recognition, alarms, and anti-collision mechanisms, pilots are able to navigate through low visibility environments like never before. (Photo credit: Abyssal)*

» *Real-time simulation is an essential part of bringing fully autonomous operations to market in a safe and cost-effective way. (Image credit: Abyssal)*

| FEATURE |

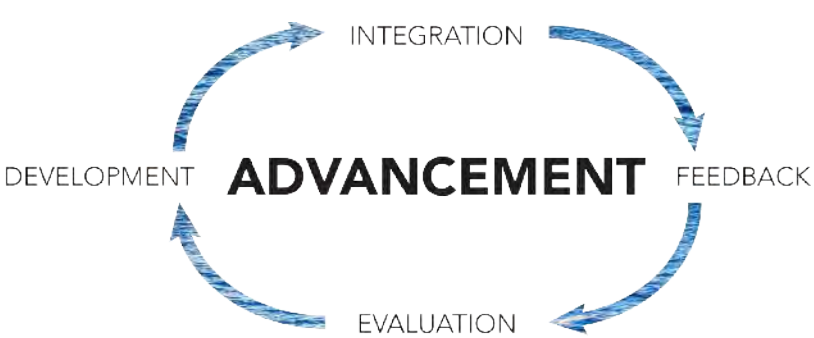
THE FUTURE OF **UNMANNED WARFARE**

By Dawn D'Angelillo, *Marketing Director, Greensea Systems, Inc.*

The purpose of unmanned warfare is to keep the warfighter out of harm's way. Greensea's motivation is that our technology will be used to save a life and that, should a device be triggered, a robot is destroyed, not a family. But beyond keeping lives safe, there is also the economic impact of protecting human resources. The U.S. Navy estimates that it costs approximately $2.5 million (and 9 years) to assess, select, and train an EOD Technician[1]. Our technology isn't about replacing a diver with an ROV or a pilot with a drone—it's solving the whole problem of providing robust, reliable solutions, and building the ability to scale, adapt, and evolve as the threats to our soldiers change. In Greensea's opinion, there's only one path forward and that's through open architecture technologies.

Greensea has spent more than a decade building and perfecting OPENSEA, our open architecture framework, upon which all of our products and services are built. Being an open architecture platform makes it scalable, flexible, and severable. OPENSEA allows us to develop software and hardware for projects as diverse as aerial drones, subsea probes intended for space exploration, work-class ROVs, and our hull crawler. More importantly, it allows anyone (manufacturers, militaries, innovators) to fast track development by leveraging the progress made by a community of developers before them. Greensea's collaboration cycle emphasizes rapid and continuous acceleration of development with our partners.

Unmanned warfare is a huge umbrella. Greensea is involved in two military strategies, explosive ordnance disposal (EOD) and Special Forces (SOF), the remainder of this article will focus on the strategies that we understand well. The problems addressed are not unique to EOD/SOF and could be applied to all unmanned solutions both military and commercial.



» *Greensea's believes that open architecture technologies represent the only path to advancement.*

KEEPING THE EOD TECHNICIAN SAFE

Robotics have been used in maritime mine countermeasures and EOD for years. While ROVs are becoming a vitally important part of the EOD Technician's capabilities, they do not provide safe standoff separation from threats and their operation is not scalable to a larger, or remote, operator base. Greensea is developing a solution, called SAFE C2, that is agnostic to hardware and communications methods and is open to current and future data transmission and ROV systems. SAFE C2 is based on EOD Workspace, an operating platform specifically developed for ROVs used in EOD operations and built on OPENSEA.

A standoff command and control solution is a new concept to the operation of ROVs for EOD applications and the exact requirements are hypothesized but currently unknown. Since solutions for the warfighter are needed quickly, they require a development process that can rapidly drive to a field-ready solution. Greensea employs an agile development process based on continuous development, evaluation, and requirement definition. OPENSEA can deliver a solution that is:

- **Flexible:** Able to adapt to rapidly changing development requirements, lessons learned, and emerging technology.
- **Scalable:** Can scale to allow for greater force involvement, multiple asset control, and multiple stakeholders.
- **Severable:** Built on previous technical investments, preserve a training base, and include new technologies and technical stakeholders as required.

There are three primary components that need to be addressed in order for a long-range control solution to be viable:

[1] *The Primer - Navy EOD Quarterly, Issue 2, January 2020.*

» *EOD Workspace configuration with long range standoff module, vessel management module, and tether management module installed. (Image credit: Greensea)*

data transmission and management between the standoff operator and the ROV, situational awareness and command and control, and tether management.

We take a simple approach to data transmission and management: send less data and send only the data needed. This is accomplished by having the ROV perform low-level autonomous functions (stabilization and piloting aids), high-level autonomy (automating common tasks), and automatic target recognition (identify and recognize sonar targets). Commands are only sent when and if it is needed and data is dynamically allocated bandwidth based on task.

Situational awareness and command and control that is lost when the operator is not onsite with the ROV. Greensea works to improve this with data stream latency management, reduction, and stream synchronization. This ensures that even with the latency of data traveling long distances, the user doesn't experience feedback arriving out of sequence.

Removing the EOD Technician from danger requires a solution for tether and vessel management. Greensea's solution predicts the optimal amount of tether to have in the water managing the deployment vessel, the tether, and the ROV to optimally aid the execution of the task without interference. With awareness of the tether path, the operator can make path planning decisions, define watch circles and exclusion zones for the deployment vessel, and avoid tether entanglement.

Greensea is developing this technology with support from the U.S. Navy SBIR program and currently has fielded several prototype systems. The success of this technology would not be possible without leveraging the open architecture of EOD Workspace, OPENSEA, and our collaborations advancing this platform.

KEEPING THE SPECIAL FORCES DIVER SAFE

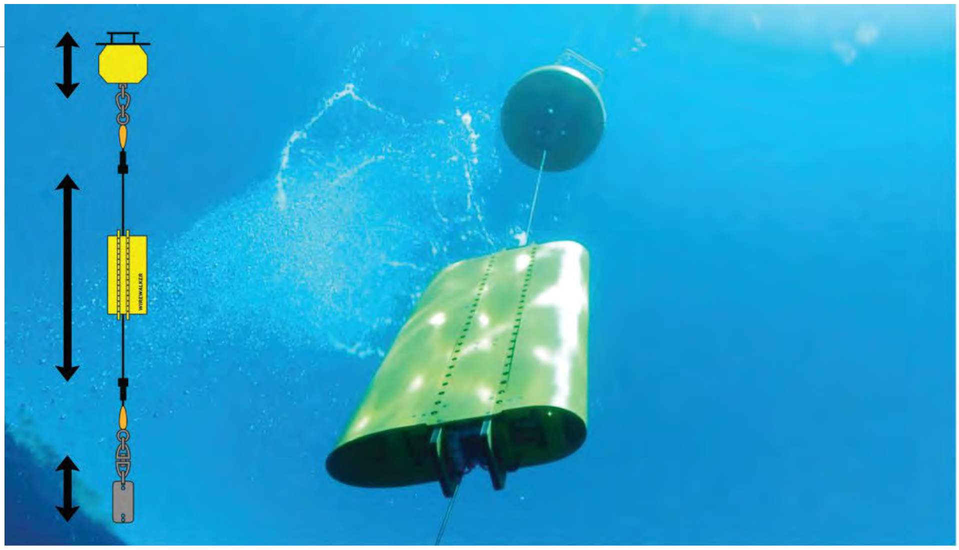
In addition to the development of the standoff command and control for EOD, Greensea's technology reduces risk in combat situations by expanding the operational capabilities of the diver propulsion device (DPD) manufactured by STIDD. The RNAV2 that is integrated into STIDD's DPD is built on the OPENSEA platform, providing navigation and autonomy to a combat diver using the DPD.

The use of autonomous systems increases operator bandwidth. Combat divers can offload navigation, piloting, and obstacle avoidance to the supervised autonomy of the DPD by pre-planning missions, coordinating missions between teams, and autonomously executing missions. Integrated navigation, vehicle control, autonomy, and sonar integration work together to provide divers a fully automated or fly-by-wire delivery system. Divers can choose to transit to predetermined locations "hands-free" at up to 4 knots or send the vehicle completely unmanned. Using Workspace, divers can easily monitor progress to their destination, battery power, manage alarms, and even communicate with team members.

THE FUTURE MEANS CHANGE

The future can't be discussed without addressing the only truth that is known—the future means change. Anything that exists now will be improved and eventually replaced. In order to plan for the future, change needs to be part of the equation. Building upon an open architecture platform, like OPENSEA, is the only way to include change into the equation. To learn more, visit www.greensea.com.

» *Greensea Crawler on VideoRay MSS Defender (Photo credit: Greensea)*



» A Wirewalker harnesses the energy in mooring motion to rapidly profile the ocean (left, photo and inset). Internally recording instruments can be mounted on the profiler frame. Ballasting (right) is accomplished by adding blocks of foam until the rise rate of the package is satisfactory. Here, the Wirewalker is shown with protective instrument covers removed. (Photo credit: Del Mar Oceanographic

| FEATURE |

THE FUTURE OF **HIGH-RESOLUTION OCEAN MONITORING**

By Rob Pinkel, *Del Mar Oceanographic*

and Chris Kontoes, *Del Mar Oceanographic*

A scale model of the Pacific Ocean would look much like a sheet of paper: roughly five thousand times wider than it is deep. It takes about one to ten years for a parcel of water to travel transoceanically, from Japan to North America for example. Transiting the short dimension of the ocean, top to bottom, takes one to ten thousand years.

The extreme isolation of one depth in the sea from the next is a result of the seemingly tiny one percent difference in the density of the warm surface waters relative to colder more-saline waters at depth. Indeed, whether in coastal or open ocean settings, the ocean is segregated into a myriad of density strata or "layers," with each playing a different role in determining the physical, chemical and biological operation of the planet.

To understand how the ocean works, and to predict its evolution under a changing climate, one must observe these various strata as they swirl slowly through the ocean interior, tracking their interaction with neighbors above and below. This measurement challenge is greatly complicated by the fact that the layers are being vertically elevated and depressed by passing internal waves on a time scale of minutes to hours. Fixed-depth observations see the combined effect of true ocean evolution and the reversible oscillations of passing waves.

Early efforts to probe the depths of the sea were ship-based, using Nansen bottles to sample at a few discrete depths. These were superseded by electronic instruments in the mid-late twentieth century. Sadly, the cost of using ships for long-term monitoring is very high. In the late 1980s Prof. Russ Davis of Scripps developed a buoyancy-driven profiling float to track the evolution of the ocean interior. His early efforts have grown into today's global fleet of more than four thousand ARGO floats, each profiling the upper two km of the ocean at 10-day intervals under battery power. Collectively, ARGO monitors the four-dimensional evolution of the ocean with ~500 km horizontal resolution. An additional fleet of ~100 floats is now being created, with bio-geochemical sensors augmenting the ARGO CTDs to study the ocean's role in the carbon cycle.

Typically, higher-density sampling is required to determine how an ocean process works than to monitor process evolution. A further reduction in cost, both in dollars and in

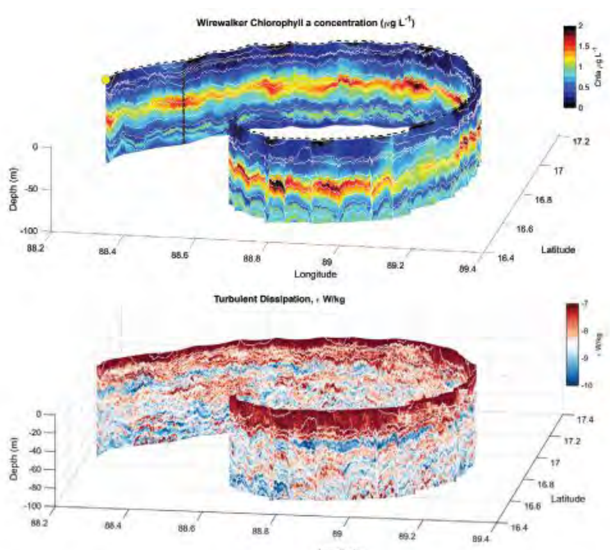
energy, is necessary if our predictive capability is to be extended. Is there a middle ground between diesel powered ships and battery powered vehicles for collecting high resolution data?

WIREWALKER

Del Mar Oceanographic is harnessing the power in ocean waves to provide rapidly (~10 m per minute, round-trip) profiling instrument systems to the marine science and monitoring communities. The Wirewalker (WW, Figure 1) rectifies the motion of a vertical wire suspended from a surface float, ratcheting downward along the oscillating wire until reaching a user-prescribed depth.

There, the positively buoyant profiler releases its grip and free-ascends at ~0.5 m/s, completely decoupled from vertical mooring motion. The extremely smooth ascent enables high-resolution observations of ocean turbulence, optical layering and other parameters that are not measurable from traditional surface moorings. At a user-specified upper profiling limit, the ratcheting mechanism re-engages and the Wirewalker initiates its next profile. Any suite of internally-powered and internally-recording sensors can be mounted on a WW and deployed. In contrast to buoyancy driven vehicles, ballasting is easy, accomplished by inserting foam blocks into the vehicle frame until a target ascent-rate is attained.

Wirewalkers have been deployed globally in missions that range from pollution outfall monitoring and coastal observing to detailed bio-physical and acoustic process experiments. Most commercial sensors and many custom ones have been aboard (Figure 2). Typical missions range from profiling to 500 m in the deep sea, at 30-50-minute intervals to coastal profiling in 20 m water depth with ~15,000 profiles per month.

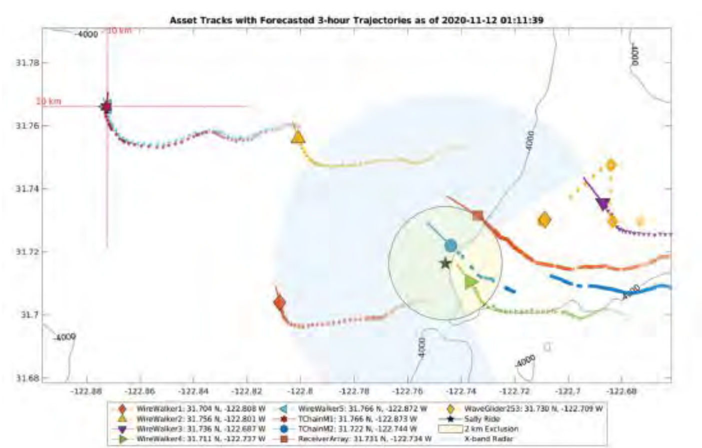


» *A 13-day record of chlorophyll fluorescence (top) and turbulent dissipation (bottom) obtained as a Wirewalker drifted around a cyclonic eddy in the Bay of Bengal. Temperature, salinity, solar irradiance and optical scattering were also measured. In the past, such high-density multi-sensor sampling could only be obtained from a ship. Here the Wirewalker captured the depth-time variability while the ship conducted a coordinated spatial survey. The cost of a complete Wirewalker system, including a quality CTD and inductive / Iridium telemetry, is comparable that of a single day of ship-time. (Courtesy of Drew Lucas, SIO. Turbulence sensor provided by J. Moum OSU.)*

For a modest increase in system complexity, onboard sensor data-streams can be merged and inductively telemetered to the surface buoy for Iridium or GSM transmission. The coming of low-earth orbiting satellite communications systems will be transformative, enabling the transmission of highly detailed data sets globally at low cost. The Wirewalker is perfectly positioned to exploit this capability.

HARNESSING WAVE POWER

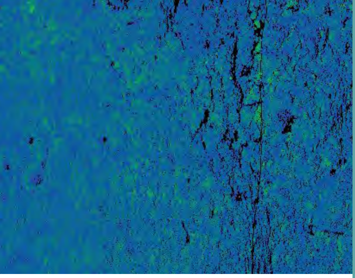
While the Wirewalker does not use batteries for propulsion, the onboard sensors do require power. Battery capacity sets the present limit on mission duration. However, the same motion of the mooring line that propels the Wirewalker can also be used to generate electricity. Working with a team at Scripps Institution of Oceanography, a wave-powered electrical generator is being developed for the Wirewalker. Here, the goal is not to "light up a small city," but simply to generate 1-10 W. In this application, wave-electrical energy conversion is an attractive technology, soon to be operational for the Wirewalker.

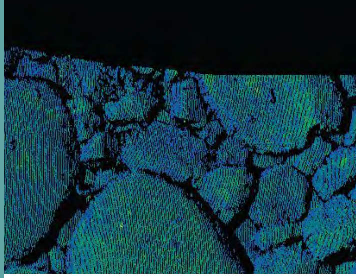


» *For intensive space-time coverage, an array of Wirewalkers can be deployed, either moored or free drifting. As this article is written, the Scripps RV Sally Ride (Star symbol above) works amid a free drifting cluster of five Wirewalkers, profiling 1-500 m, and a number of other autonomous assets. In this experiment, the spatial array is a significant force-multiplier, increasing the value of the shipboard effort by providing high resolution spatial context. Removing the ship, such spatial arrays, moored or drifting, can significantly augment global monitoring systems. (Image credit: Courtesy W. Hodgkiss, SIO.)*

When coupled with the coming satellite data-transmission constellations, the Wirewalker can complement existing global monitoring arrays, providing a ~10 profile per day capability to one-kilometer depths for extended periods. The Wirewalker's simple "bolt it on and try it out" sensor integration capability enables researchers with modest technical support to get the data they need. The extreme variability in ocean structure, from layer to layer, stratum to stratum, becomes a key signal, not an obstacle in the quest to understand, monitor, and predict ocean processes.

For more information, visit *www.delmarocean.com.*





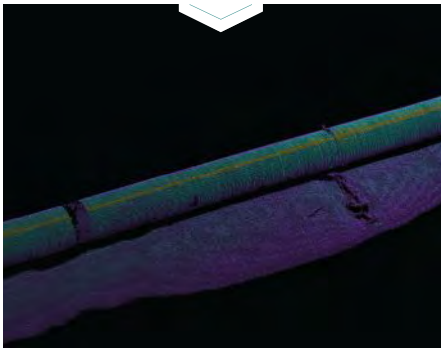
| FEATURE |

THE FUTURE OF SUBSEA SENSORS WILL ENABLE AUTONOMY

By Chris Gilson
General Manager, 2G Robotics

In the world's current environment, the drive towards remotely operated surveys has never been greater. As some operators attempt to make this shift, however, it is becoming evident that cost-efficient, untethered operations require more than just autonomous vehicles—they also require autonomy enabling sensor solutions. 2G Robotics' optical AUV payloads are enabling operators to realize true autonomous capabilities that are catalyzing the shift towards remote operations.

The offshore industry is now coming to terms with the challenges associated with the COVID-19 pandemic, and companies are looking for innovative ways to protect staff and reduce operational costs, while maintaining the effectiveness of existing survey approaches. This has led to an urgent need for operationalizing the concept of remotely operated surveys and shifting to new methods that require fewer offshore staff.



» *Dynamic Laser Scanning Model of a Pipeline (Image credit: 2G Robotics)*

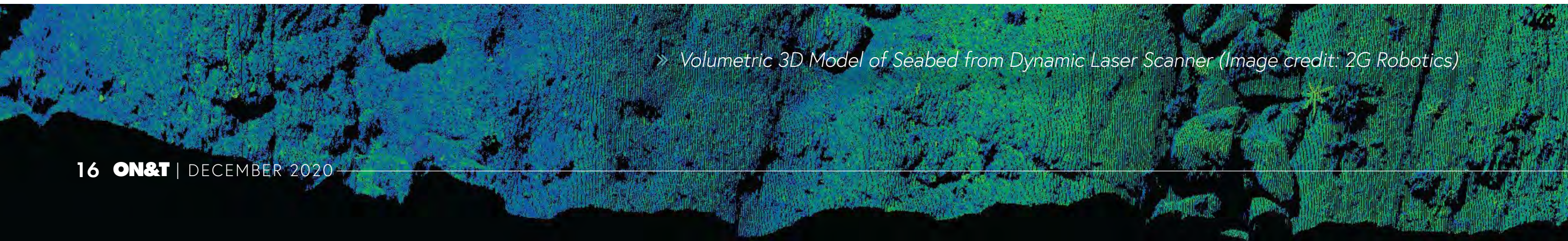
THE RISE OF THE AUV

For the last decade the offshore industry has been slowly embracing the use of large Autonomous Underwater Vehicles (AUVs) as an alternative to work-class Remotely Operated Vehicles (ROVs), to provide faster and more cost-effective surveys for particular applications, like pipeline inspection. In 2018, the Westwood Global Energy group's *World AUV Market Forecast* predicted that the demand for commercial AUVs would grow by 74% by 2022, mainly in the offshore energy, defense, and research industries, and this trend has realized significant innovations in offshore operations.

While the platforms themselves are autonomous, we still find ourselves a long way from fully autonomous operations. Platforms aren't achieving their true potential because even though they execute the mission with minimal human intervention, vehicles still require large crewed ships for vehicle deployment, recovery, and manual data review onboard the vessel to deliver the survey goals. To achieve the goal of remote offshore operations there are two core innovations that are needed to deliver this remote revolution: smaller vehicle platforms and autonomy enabling sensors.

ENABLING THE REVOLUTION

First, smaller AUVs and ROVs must become more capable. The use of smaller vehicle platforms reduces capital costs and enables deployment from cost-effective unmanned surface vehicles (USVs). In a transition period they can be deployed from smaller vessels with reduced staffing and environmental impact. These vehicles have made great inroads in recent years, gaining longer endurance, improved navigation, and more powerful thrusters to deal with high current, but their ability to deliver high-resolution survey data continues to lag.



» *Volumetric 3D Model of Seabed from Dynamic Laser Scanner (Image credit: 2G Robotics)*

With our new RECON AUV payloads, 2G Robotics is leading the way in small AUV sensors by delivering modular and power-efficient optical solutions that achieve resolutions and accuracies previously only possible on large vehicles. The RECON CS and LS payloads bring long range, crisp 4K imaging, and high accuracy dynamic laser scanning to smaller vehicle platforms, expanding their capability to perform tasks such as pipeline inspection, marine research area mapping, and remote identification for naval mine countermeasures.

Sonardnye's Solstice is another perfect example of this evolution, delivering a power efficient and high-resolution multi-aperture sonar that delivers data quality previously unattainable on small AUVs.

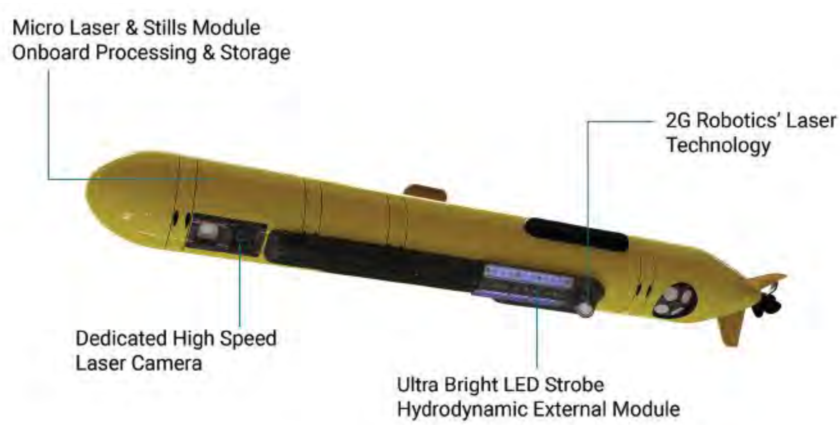
Second, the sensors themselves must enable autonomy. It is becoming evident that on the path to fully remote operations the vehicle platform is just one piece of the puzzle. As we transition towards resident robotics, or onshore controlled USV surveys, then it is no longer possible to simply recover the vehicle, download all the data, and spend hours manually reviewing it. The vehicle must be able to execute unsupervised decision making to turn this vision into a reality, not only for mission efficiency like target reacquisition, but also to limit the amount of data that must be wirelessly transmitted back to shore. Unsupervised decisions require high-quality real-time datasets, and computationally efficient autonomous data analysis, something that has historically not been prioritized by sensor manufacturers.

ENABLING REAL-TIME DATA

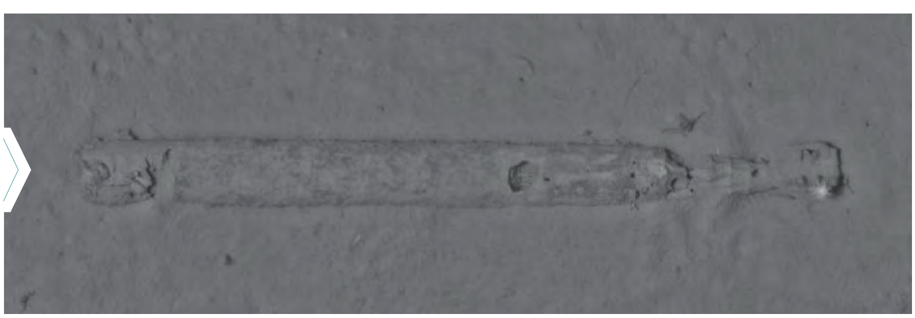
2G Robotics is again looking to overcome these challenges by commercializing new power-efficient processing electronics to deliver clean 3D laser data in real-time to enable vehicles to achieve new autonomous capabilities like laser-based pipeline tracking, through-the-sensor navigation, and 3D target recognition. With its line of AUV specific stills cameras, 2G Robotics has made real-time onboard image enhancement a reality, delivering optically-corrected and light-levelled colour images to onboard deep learning algorithms to achieve capabilities like on the fly defect detection and automated vehicle docking. We need to put days of staff clicking through ROV video footage or trying to interpret low-resolution sonar data behind us.

It is these new autonomous capabilities, enabled not by new vehicles but by new sensor technologies, that will make the vision of remote offshore operations a true reality. New innovations in subsea sensor technologies will drive the industry to take full advantage of autonomous systems to save time, lower operational costs, and mitigate the new risks associated with offshore staff.

To learn more, visit *www.2grobotics.com* or contact sales@2grobotics.com.



» *2G Robotics' RECON LS Laser Scanning and Stills Imaging AUV Module*



» *Stills Image Mosaic (6 Images) of a Torpedo Captured from an AUV at 4 Knots (Image credit: 2G Robotics)*

FEATURE

THE FUTURE OF DEEP OCEAN RESEARCH

By William Kohnen,
President, Hydrospace Group Inc.

The future of deep ocean research charts a parallel course to how satellite systems have revolutionized global science and communication over the last fifty years. Today, satellites are instrumental to global environmental planning, positioning, and connectivity. We need a similar infrastructure for our oceans. The prospect of a network of high-reliability subsea systems designed to support deep ocean research poses a monumental challenge—in more ways than one—but, in the same spirit that compelled Jules Verne to imagine the inconceivable over 150 years ago, the time to prioritize such efforts is now.

The satellite concept was imagined in the mid-1950s by the Rand Corporation for military purposes. Today, there are satellite constellations orbiting the globe that provide continuous and comprehensive coverage. The ability to connect, communicate and operate global sensors through multiple satellite networks allows us to live, work and innovate within this seamless infrastructure. Given how ubiquitous this network has become to our daily lives, couldn't we imagine similar for our oceans?

Yes, but there are unique challenges. While electromagnetic waves travel through the vacuum of space—providing a wireless connection between buildings, planes, and satellites in outer space, all the way to the edge of our solar system—the same rules do not apply for hydrospace. Radio waves cannot travel through water in the same fashion. Sound waves do, but the bandwidth of signals is limited to a speed one million times slower than that above the surface.

» *Certified Acrylic Pressure Vessel for Subsea Habitat (Photo credit: Hydrospace Group)*

Traditionally, ocean research has relied on ships to traverse new frontiers, chart various locations, and collect relevant data. It is relatively slow and tedious task but has rewarded us with some significant discoveries, including the movement of tectonic plates, seafloor mountain ranges, hydro-thermal vents, and much more. Similarly, breakthroughs in acoustic sensing continue to accelerate our exploration of offshore resources. But we need more.

UNDERWATER CONSTELLATION

So, what's next? Short of global quantum computing capable of penetrating our deepest waters, we need another "constellation" of oceanic instruments designed to measure, study, and communicate in hydrospace.

Rather than being dependent on topside vessels, deep ocean research requires a new generation of failproof, interconnected systems with long-term submergence capabilities, stationed on the ocean floor or in the water column. Technically speaking, this is a multi-decade endeavor which will rely on generational collaboration. Certain nations and government agencies have responded by setting up research and funding groups and are pushing ahead to champion innovation in subsea vehicle technology and instrumentations, as sub-systems for communication, navigation, and survey.

Notably, the United Nations has proclaimed a Decade of Ocean Science for Sustainable Development (2021-2030) to support research in ocean health. This effort calls on ocean stakeholders worldwide to support a common framework of ocean science for the sustainable development of the ocean around the globe. SEABED 2030 was also launched in 2020 as an international, collaborative project between the IHO/IOC General Bathymetric Chart of the Oceans (GEBCO) and the Nippon Foundation that aims to facilitate the complete mapping of the world's ocean floor by 2030.

MULTI-LAYER MAPPING

Every long journey starts with a first step. Today, it is generally accepted that only 19% of the global seabed has been accurately mapped, and that fully understanding how marine environments influence life on Earth starts with revealing its topographical qualities. However, beyond bathymetry, this is a multi-layer mapping exercise: The second layer must map life form composition, followed by a third layer to map the distribution of fauna and flora and the ecosystems they maintain. The fourth layer would consist of

analyzing the health of these marine ecosystems (shallow and deep), while the fifth should examine ecosystems in the water column.

Exploring hostile ocean environments in the name of mapping these five layers will hinge on the collaboration of all major fields of advanced science and engineering. Systems, components, and sub-systems must be reliable, self-maintaining, and intelligent. Some of this will come from AI and Machine Learning, while others rely on human heuristics. This will surely require a full spectrum of large-scale subsea drones, strings of instruments and robot deployments, and innovations in manned submersibles, especially for layers 3, 4 and 5. What they all have in common is the need for high reliability systems. I often think of the system designs we made 30 years ago for Mars exploration, intended to carry out a 5-year mission. Today, when considering system designs for 5-year mission life at the bottom of the ocean, Mars appears a lot more benign; with a light atmosphere, some dust, but surely not encumbered by millions of biological life forms and the sorts of corrosive surroundings intent on exposing any weakness of human construct.

DEEP-SEA SYSTEMS

The only way we can foreseeably achieve global subsea coverage would be via a highly engineered "constellation" of deep-sea systems. This demands devices be suitable for long-term residency and for all components to be exceptionally reliable. Critical components and sub-systems include:

1. Power plant systems and components: Batteries, super capacitors, power generators, energy management systems for AUVs, ROVs, and seafloor stations

2. Electric motion control and components: Electric motors, propulsion systems, drive mechanisms, winch drives, valve actuators, pump drives, and pointing mechanisms

3. Robotic systems: Electric robotic manipulators for high performance capability and long submergence reliability

4. Pressure vessels and components: Pressure vessels for human occupancy, acrylic pressure vessels, hi-rel deep ocean pressure hulls, and housings and tanks for special applications.

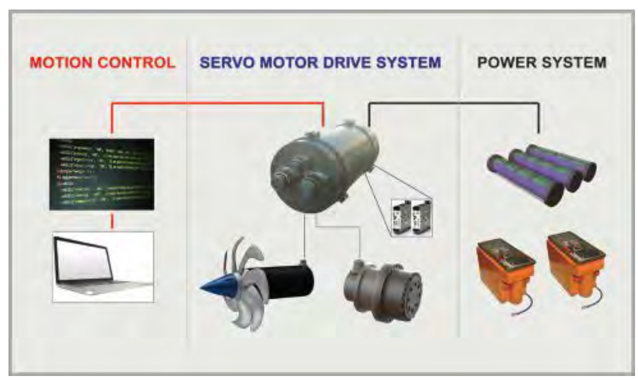
5. Manned submersible vehicles for certified, safe and reliable exploration

Hydrospace Group specializes in high reliability system design and our experience bridges from space exploration to, since 1995, subsea innovation. Hydrospace provides proven solutions for all types of systems (manned and unmanned), and expert engineering for power storage, propulsion, actuation, navigation, robotics, pressure vessels and crewed vehicles.

So, in many ways, the future is what we determine it to be. Take Jules Verne, for example: Nautilus—his fictional submarine in Twenty Thousand Leagues Under the Sea may have been his most fabled creation, but the true magic came from its power source. It was propelled by "electricity"—a concept that was little explained and must have sounded futuristic. Turns out, he was close; you need pressure vessels and electricity. As experts in electricity, pressure vessels, and underwater vehicles, the team at Hydrospace Group sees an exciting future bound only by our imagination, and we remain committed to providing a continuous flow of innovative solutions for all types of subsea critical mission systems and components.

For more information, visit: www.hydrospacegroup.com

» *Deep Ocean Electric Brushless DC Rotary Actuator (Photo credit: Hydrospace Group)*



» *Electromechanical & Battery Systems for Deep Ocean Vehicles and Instrumentation (Image credit: Hydrospace Group)*

» *Aurora Deep Ocean Exploration Submersible for 3 Persons (Photo credit: Seamagine Hydrospace Corp)*

| FEATURE |

THE FUTURE OF AUVs FOR SURVEY

By Chris Echols, *Global Business Development Manager, Oceaneering*

and Jami Cheramie, *Subsea Robotics Product Manager, Oceaneering*

Advances in secure, reliable communication networks, software, batteries and positioning sensors, have pushed forward the development of resident and autonomous vehicles in the near-term. Because of these advances, these vehicles can accurately position themselves and receive missions to gather data and safely send it back to shore for analysis.

In the long-term, autonomous underwater vehicles (AUVs) for survey will have to become more autonomous and work for longer durations than currently available. Oceaneering has been working towards advancing subsea residency and autonomy for AUVs with our Freedom™ Autonomous Subsea Vehicle.

ADVANCING SUBSEA AUTONOMY AND RESIDENCY

Oceaneering's Freedom™ Autonomous Subsea Vehicle combines the work class functions of a ROV with the speed, range, and maneuverability of an AUV. Freedom is supported by a docking station at the seabed and can operate in two modes: remotely piloted via tether to provide real-time control—or operated in an autonomous and tetherless mode, using battery power.

Freedom has a working range of 200 km, a working depth rating up to 6,000 m, a maximum speed of 6 knots, survey speeds of 1-3.5 knots, survey altitudes of 1-5 m for inspection and 8 m for reconnaissance, and subsea deployments of up to six months. Because the system can stay subsea for longer durations and be programmed to conduct new missions and even sub-missions, carbon emissions can be reduced because there is no need for a support vessel to stay nearby while the vehicle conducts its work.

We have spent three years focused on Freedom's design, testing, and qualification. Our advanced software has been a big component of Freedom's autonomy. We set out to develop our supervisory control software for multiple types of autonomous vehicles, including land-based automated guided vehicles (AGVs), work class autonomous underwater vehicles (AUVs), and ROVs. The software is operating system agnostic to support varied mission types. With an agnostic approach, we can easily roll out updates to the entire fleet.

Freedom's supervisory control software enables the vehicle to carry out low altitude inspections for pipeline surveys, tracking pipelines 1 m off the seabed to provide high resolution data. The software provides the vehicle with a heightened level of obstacle detection, autonomous obstacle avoidance, and situational awareness. These features allow the vehicle to re-plan its route and re-engage with the tracked pipeline. The software also allows the Freedom vehicle to recognize pipeline features including free-spans, depleted anodes, mattress crossings, and anomalies which can trigger sub-missions for further inspection, thus avoiding the requirement for subsequent inspection operations following the initial survey.

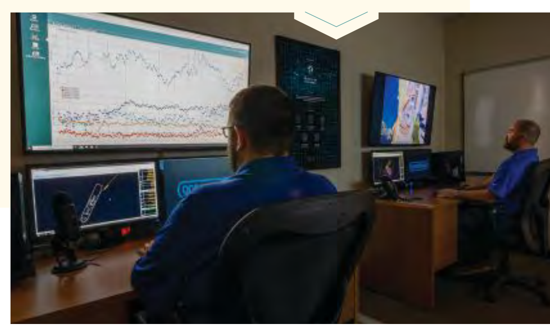
In September 2020, Freedom completed the industry's first autonomous subsea docking operation using an operator's newly developed Underwater Intervention Drone (UID) docking station at our test facility in Norway.

While in autonomous mode, Freedom can locate the docking station and adjust its orientation using integrated machine vision. This technology enables Freedom to analyze both heading and distance to ensure a perfect landing. Once docked, Freedom's inductive connectors allow it to recharge its batteries, link to onshore locations to download data, and receive new mission information.

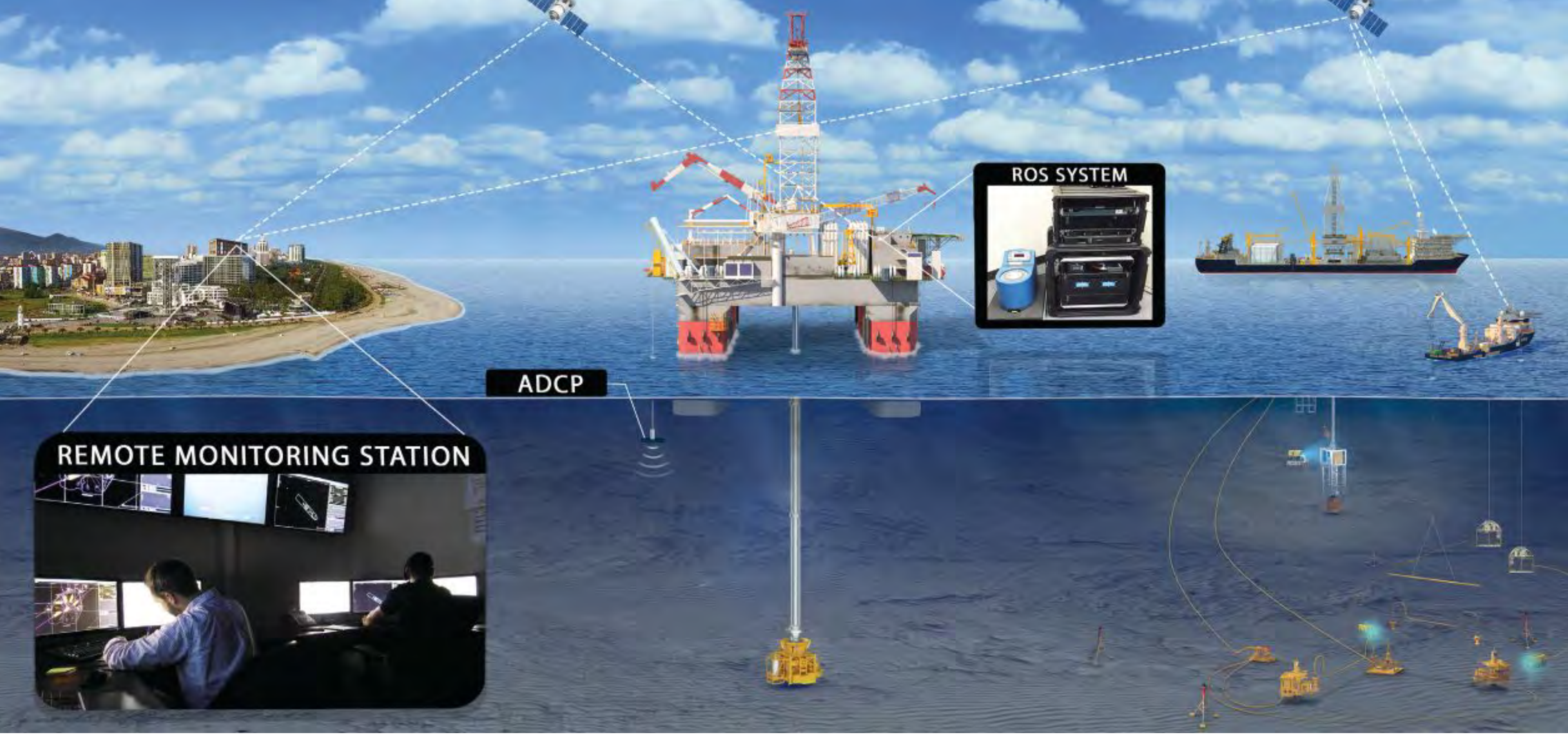
ADVANCING REMOTE OPERATIONS

Oceaneering has also been working toward furthering remote operations for the offshore energy industry. Remote operations make it easy to down man and reduce mobilization and logistics costs. Subject matter experts (SMEs) can work from a dedicated onshore base and safely and intelligently communicate with personnel on the rig or vessel.

Recent advances in offshore communication networks are ensuring that resident remotely operated and autonomous vehicles are a trustworthy option for carrying out offshore



» *Onshore-based personnel observe ROS operations for an operator offshore South America from dedicated Remote Control Monitoring Stations (RCMS) in Houston, Texas. (Photo credit: Oceaneering)*



» An illustrated overview of Remotely Operated Survey operations. (Image credit: Oceaneering)

operations. Advanced subsea vehicles are benefiting from increased 4G offshore coverage along with faster, stable, and more cost-efficient satellite communications. Additionally, we are seeing more offshore installations with direct fiber to shore connectivity allowing for lower latency and higher fidelity connections.

Our Survey and Positioning Solutions group launched Remotely Operated Survey (ROS) services in 2016 when we were first approached by a major U.S. operator to find a long-term, cost-efficient solution for offshore drilling rig moves.

Reliable data and communications between the rig or vessel and the onshore base are the backbone of the ROS solution. The required bandwidth is determined by project scope and some operations can be run with as little as 256kbps of bandwidth on the rig or vessel's existing internet access. However, when the campaigns are more advanced, more data bandwidth is necessary to conduct remote monitoring operations and maintain constant contact with the Dynamic Positioning Officer, ROV pilots, and party chiefs.

Our ROS solution can be used to execute exploration work, floating production storage and offloading (FPSO) vessel hookup, plugging and abandonment, development, re-latch, and re-spud activities. We also conduct remote inertial jumper metrologies, remote inertial marker buoy sets, and remote monitoring of Acoustic Doppler Current Profiles (ADCP) data.

» Oceaneering's Freedom™ autonomous subsea vehicle in the water at Oceaneering's dedicated testing lab at Tau, Norway, in July 2020. (Photo credit: Oceaneering)

In the years since launching our ROS service, we have amassed over 150,000 hours of operations with 99.9% uptime in data transfer and completed over 100 individual projects.

At our Center for Survey Excellence in Lafayette, Louisiana, we built a dedicated Remote Control Monitoring Station (RCMS). The facility is manned 24/7 to provide global support for our ROS operations. Clients can watch live operations from our RCMS, or we can provide a remote link to view from their offices.

THE WAY FORWARD

Autonomous vehicles have much further to go to become true resident autonomous systems. The future of autonomous vehicles lays with machine learning and artificial intelligence, which can give the vehicle the ability to make educated decisions depending on the scenario encountered, as well as finding additional reliable power supplies to boost the vehicles' subsea navigational capabilities and long-term endurance.

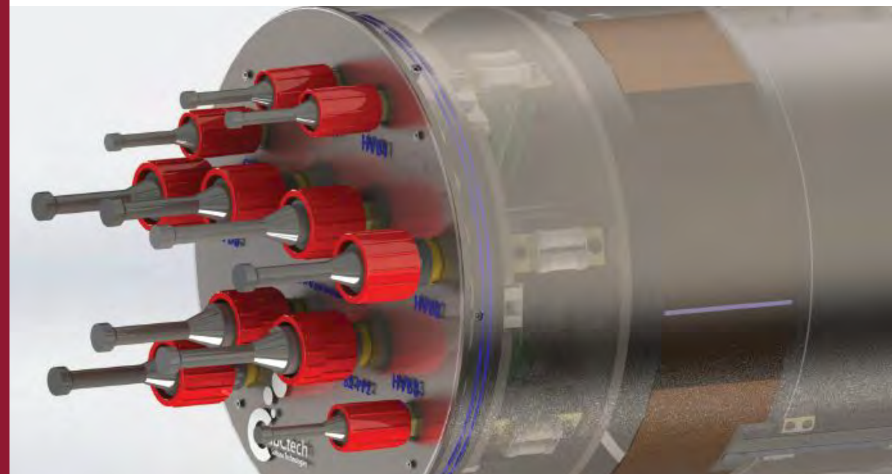
Oceaneering sees the future of offshore energy industry robotics as a combination of man-in-the-loop operations, like our traditional remotely operated vehicles (ROVs), as well as autonomous capabilities, without anyone in direct control of the vehicle, being used to complete parts of a work scope. We believe that the line between what is remote controlled and what is autonomous will become increasingly blurred over the next few years, so much so that we anticipate every vehicle must have the capabilities to operate in both scenarios.

To learn more, visit *www.oceaneering.com.*

» An illustration of Oceaneering's Freedom™ autonomous subsea vehicle scanning a pipeline. (Image credit: Oceaneering)

FEATURE

THE FUTURE OF **ALL-ELECTRIC SUBSEA EXPLORATION**



» *Figure 1: Series 416 battery system with charger, power distribution unit PDU and 10 kW converter. (Image credit: SubCtech)*

By Stefan Marx, *CEO, SubCtech GmbH*

Subsea Oil and Gas production facilities are accelerating their efforts to transition from electrohydraulic to all-electric operations. Reasons for this shift are reduced complexity, reduced power demand—which reduces the umbilical cross section—and greater reliability.

This results in a significant reduction to both CAPEX and OPEX, which is especially important when it comes to future deep-sea installations and remotely operated assets in ice regimes, as well as the retrofitting of shallower wells.

Because these existing systems rely on electrical power, a number of challenges must be solved. First issue, existing subsea units cannot deliver the needed power. Second issue, increased reliability and operational safety must be guaranteed.

Battery-powered subsea UPS systems relieve the umbilical in moments of increased power demand and guarantee safe operation and shut-down, in the case that topside power is lost. Thus, the UPS battery system is one key technology for a successful transition from hydraulic to all electric.

SUBCTECH BATTERY TECHNOLOGY

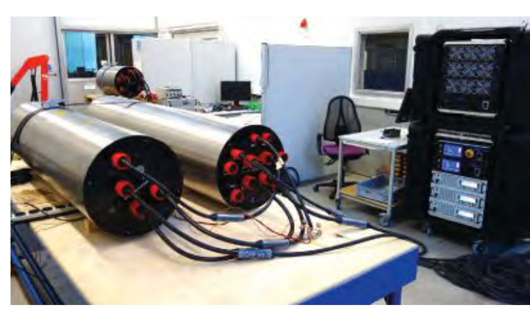
Since the first delivery of a subsea Li-Ion battery in 2006, SubCtech has consistently developed safe, reliable and efficient Li-Ion batteries. This includes underwater batteries for vehicles, such as AUVs and ROVs, which have been certified according to MIL-STD or DNV GL since 2013. Since 2012, SubCtech has been a qualified supplier according to API17F or ISO 13628 of Li-Ion batteries to the offshore industry.

SubCtech is pursuing the approach of deeper system integration, in which the entire battery system and electronics are integrated together with cylindrical Li-ion cells in a titanium or duplex steel housing (see Figure 1). Round cells can optimally fill the available limited space of pressure vessels. The comparatively small cells offer flexibility in the mechanical arrangement and can be connected in parallel or in series depending on the application. This enables highest flexibility in performance and dimensions, as well as higher energy densities (kg/Wh) compared to other batteries on the market. The large number of individual round cells is connected in a vibration-proof manner using a specially developed process. This is only possible with small 18650 cells and not with larger Li-Pol or pouch cells. The high number of cells is monitored by a sophisticated battery management system (BMS). Depending on the application profile of the battery, cylindrical cells of the same form factor but different chemistry can be used and, therefore, the battery can be optimized for high power, low self-discharge or high capacity.

MODBUS RTU, CAN, CANopen and, in the future, also TCP are used as the data interface. Safe communication channels are implemented for batteries rated with SIL. The new embedded CIM (Customer Interface Module) allows an easy adaptation to the application without having to re-qualify.

MODULAR BATTERY ARCHITECTURE

The recently launched large 416 series supplements the well-known 260 and 310 series for vehicle or storage systems. The number 260, 310 and 416 simply indicates the diameter of the battery without canister/pressure housing. The energy is scalable by stacking different numbers of submodules, so called SmartPowerBlocks™. Power electronics for charging, distribution and voltage conversion, as well as data monitoring and interface modules can be added to the titanium or super-duplex steel housing completing a battery power system.



» *Series 416 battery system testing. (Image credit: SubCtech)*

Thanks to the flexible concept, the 416 series can be scaled in a wide range: Voltages between 14 V and 600 V are offered. Modules can be combined up to 1000 kWh. The batteries are optimized for high power or high capacity.

Systems of up to continuously 38 kW output power at

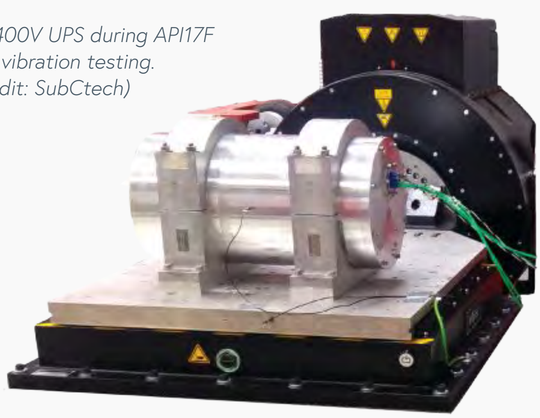
430V and an energy of 72 kWh have been already realized inside a pressure vessel of 480 mm (W) by 2,000 mm (L), with a combined weight of approximately 500 kg.

SUBSEA CHARGING STATIONS

Subsea battery storage systems accumulate energy from topside sources and use high-power charges to rapidly recharge an AUV or eROV. SubCtech is currently working on the development of docking station technology in industrial projects (JIP) and national funding projects (EU FP7 TRACT pipeline inspection robot; cModem: University Kiel; MAUS underwater vehicle; MiRo-Base eROV with Fraunhofer and others). An embedded AUV charger for 2 x 3 kW 200-400V DC is already commercially available. Even the large storage batteries can be qualified to MIL-STD or API17F.

UPS SYSTEMS FOR ALL-ELECTRIC PRODUCTION

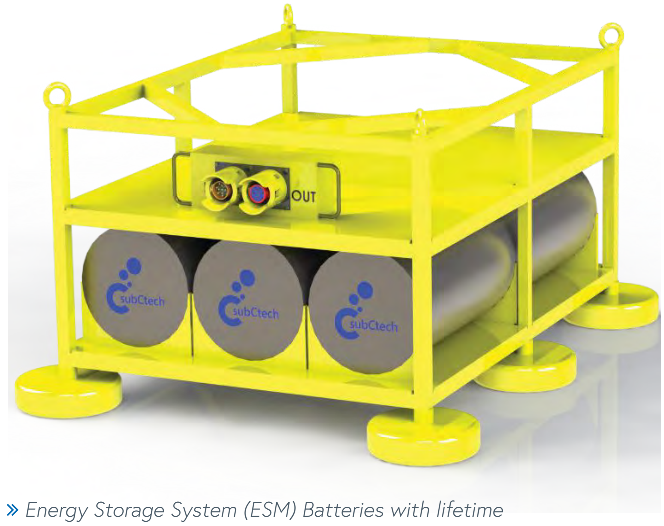
Special requirements for the offshore Oil and Gas industry have triggered the development of extremely reliable batteries with a lifetime of up to 30 years. With the API17F or ISO 13628-6 standards, batteries have to withstand rapid temperature changes as well as extensive shock and vibration tests. Such qualifications are compulsory for operations in the deep sea, as service or failure would cost millions.



» *Subsea 400V UPS during API17F shock and vibration testing. (Image credit: SubCtech)*

Following the introduction of the first "real" Subsea-UPS in 2012, SubCtech has an established track record and reputation, and today offers a wide range of products: a small 24V-UPS with predictive monitoring of the SOH (State of Health), a 400V high-energy Subsea-UPS with constant voltage and a high-power Subsea-UPS with 200V or 400V that can deliver up to 22 kW.

» *SubCtech storage and large UPS solutions for 1000 m and 3000 m. (Image credit: SubCtech)*



» *Energy Storage System (ESM) Batteries with lifetime corrosion-free titanium housings. (Image credit: SubCtech)*

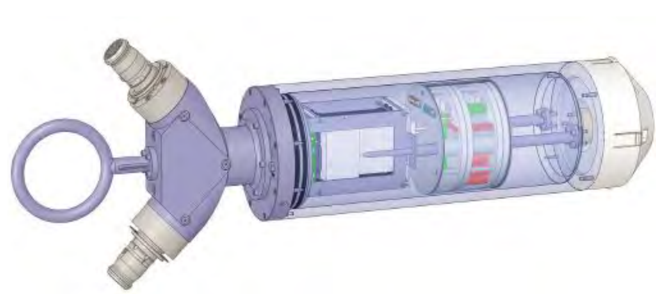
BATTERY SAFETY

Battery cells with SubCtech's Li-Ion technology not only offer cost-effective advantages in terms of energy and power density, but also safety. Their special industrial cells feature several internal safety mechanisms: an overpressure valve, a short-circuit protection, a steel housing and, in the case of the high-energy cells, a special temperature protection jacket around the electrodes.

The battery is primarily divided into safe modules. These can be scaled up and are monitored and controlled by a high-level controller (BMS). For safe systems, such as vehicles, parallel safety mechanisms and a "safety loop" are used. For high-availability applications, such as subsea production, critical states are excluded by design. SubCtech works together with certifications such as TÜV and DNV GL, considering the Norwegian NOG 070 guideline related to safety applications in the Norwegian Petroleum industry. With predictive monitoring—developed in 2014 in partnership with the University of Kiel—aging or weakening is reliably detected months in advance.

We see all-electric systems, like SubCtech's Li-Ion Subsea UPS and storage batteries, as a safer way to cut costs.

For more information, visit: *www.subctech.com.*

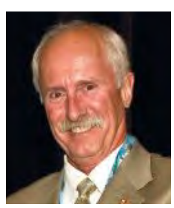


» *Subsea 24V-UPS with other control units installed into typical SEM canister. (Image credit: SubCtech)*

FEATURE

THE FUTURE OF **OCEAN MINING**

» *Polymetallic nodules are typically 4 – 10 cm in diameter and contain rare earth metals, notably nickel (1.5%), cobalt (.25%) and copper (1.25%).*



By Ted Brockett,
Managing Director,
Okeanus Science & Technology

Much has been written in recent years about the commercial prospects of the ocean mining industry and, in particular, the harvesting of polymetallic nodules from the seabed in the Pacific Ocean's Clarion Clipperton Zone (CCZ). 2020 was billed as a pivotal year during which stakeholders might see the first iteration of the Mining Code, essentially a ratified body of rules, regulations and procedures designed to oversee the prospecting, exploration and exploitation of marine minerals in the "Area", international waters beyond national jurisdiction.

But progress, as with so many industries, was hampered by the COVID-19 pandemic. Notably, a number of critical sessions at the International Seabed Authority (ISA), headquartered in Jamaica, were postponed, and while the ISA plans to meet virtually in December, momentum appears to have been lost.

However, the seabed mining community is no stranger to set-back and delay, so stakeholders remain optimistic that 2021 will be more productive in terms of establishing meaningful steps toward commercial operations, even amid mounting calls for a deep-sea mining moratorium from civil society and a variety of NGOs.

COLLABORATION NEEDED

All of this uncertainty makes foretelling the likely future challenging. After all, deep-sea mining is anything but a fleeting concern; we have been trying to establish a realistic route to exploitation since the 1970s. If lessons from the past are anything to go by though, a more orchestrated and collaborative approach may prove lucrative in the short term, for both mining operators and license holders alike. Historically, the industry has always been somewhat reserved, but there are key, long-term advantages to pooling resources. None more significant than the immediate opportunity to curb operating costs. And the costs are substantial. To mimic the CCZ pilot tests we ran at Ocean Management Inc. (OMI) in 1978, would easily cost north of $100 million today. And the risks are equally hefty, too. We encountered some very costly, unforeseen problems; in fact, on our third mission we experienced a major system failure on deployment of our nodule collector, which led to a loss of the Cutter Blade Scraper (CBS) collector, the collector instrumentation system, and the collector umbilical cable resulting in the early termination of the OMI PMT program.

Taking a more collaborative approach to mitigating risks, therefore, may seem prudent given the stakes. Further, beyond financial capital, it would allow collaborators to group certain specialisms and subject matter expertise. In other words, intellectual capital becomes the currency by which the market can prosper, collectively. This would present a marked shift in mindset given that operators have tended to be guarded in the past, especially when it comes to collector technologies. But greater transparency here could usher in fresh impetus. After all, beyond the collector, the rest of the required equipment—air lifts, pumps, vessels, on deck sorters and storage systems—are borrowed straight out of the oil and gas toolkit.

EVIDENCE-BASED DEBATE

In the short- to mid-term future, regardless of whether exploitation licenses are granted in

the next few years or not, we will see ongoing scrutiny about the environmental impacts of seabed disturbances and sediment plumes. The industry needs to find a way to address these concerns and not get hamstrung in polemic debate. Ironically, the ISA, mining operators, and even the NGOs calling for a moratorium all want the same thing: a prudent, step-by-step approach supported by robust science. This point is often lost in slanted reporting.

As encouraging as this shared will is, though, we do actually have to run fully operational in-situ tests to garner irrefutable scientific evidence. Then we need to consider these findings within a broader evidence-based context. For example, how should we evaluate the impacts of land-based mining against seabed resource extraction, when we know that land-based activities are chasing diminishing returns and depleted mining grades, while abundant resources sit atop the seafloor? We know how to harvest nodules—we just need to marshal that know-how responsibly. That has proven to be easier said than done, so, again, collaboration will continue to be the key.

NEW TECHNOLOGIES

Ocean technology, which is advancing at a pace never seen before, will also prove instrumental. Breakthroughs in autonomous systems and AI have the potential to completely rewrite how certain industries operate in remote and often harsh marine environments. The implications for ocean mining could be profound.

At Okeanus, one area we are focusing on with customers, be it for commercial, scientific, or defense application, is the development of advanced handling systems for the deployment of Autonomous/Unmanned assets, both surface and underwater (ASVs/USVs/AUVs/UUVs) and autonomous LARS/winches for automated deployment from those unmanned assets. In short, we are working towards making autonomous systems more autonomous.

From a technological perspective, the ocean industries have only begun to scratch the surface of what's possible in terms of autonomy and machine learning. In the commercial markets, we tend to think of unmanned vehicles for very specific applications, such as hydrographic survey, but navies around the world envision large unmanned surface vehicles (LUSVs)—vessels between 200 – 300 feet in length and full load displacements of 1,000 – 2,000 tons—as key assets for low-cost, high-endurance missions. So why not for ocean mining?

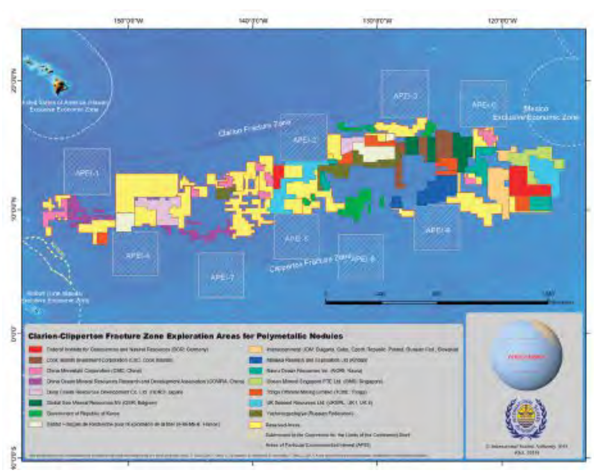
Then there is the question of resident subsea vehicles and their supporting seabed infrastructure. We already have hybrid ROV/AUV systems that can operate unassisted for months at a time. They can be set to full autonomous mode or controlled remotely, from shore. Notwithstanding the challenge of ensuring a sufficient yield, if effective for manipulating wellheads and asset integrity inspection, why not for selectively gathering and stockpiling polymetallic nodules?

Clearly, technology of this degree of sophistication comes with a hefty price tag, but as increasingly scalable options come to market it will offer deep-sea operators with much to think about as they adjust their business models to integrate emerging innovation.

There is, however, an alarming irony when it comes to the prospect of automating ocean mining operations: the CCZ is a remarkably remote location and a reliable energy source is imperative to powering manned or unmanned assets. So, the advancements of battery technology and storage will likely support, in one form or another, ever more efficient, safe and precise mineral extraction methods. And to develop and manufacture batteries at the scale and quality required, we need an assured supply of rare earth metals (e.g. lithium and cobalt) found in polymetallic nodules, lying in abundance on the CCZ's seafloor.

For more details, visit: *www.okeanus.com.*

» *Most mining proposals center around a seabed collector supported by a supply chain borrowed from the oil and gas industry. (Image credit: Blue Nodules)*



» *The CCZ, an abyssal plain spanning 5,000 km across the central Pacific, boasts average nodule accumulations of 15 – 20 kgs per square meter, at depths of up to 5,500 meters. (Image credit: ISA)*

| FEATURE |

THE FUTURE OF **REEF RESTORATION**

By Brian Smith-Fisher, *Chief Operating Officer, JW Fishers Inc.*

It was John F. Kennedy that perhaps said it best in 1962: "We are tied to the ocean. And when we go back to the sea, whether it is to sail or to watch, we are going back from whence we came." It is a sentiment that resonates with many of us who call the planet's marine environments our place of work. Now, almost 50 years later, this quote has never felt more poignant amid mounting climate change concerns.

We have long known that our ocean's coral reefs are endangered; the scale of threat was amply evidenced by a massive die-off in 2015/16. This was the third registered bleaching event of its kind and was caused by rising sea temperatures. Climate change—exacerbated by human activities—is also having a detrimental impact on reef ecosystems found in inland waters.

THE GREAT LAKES

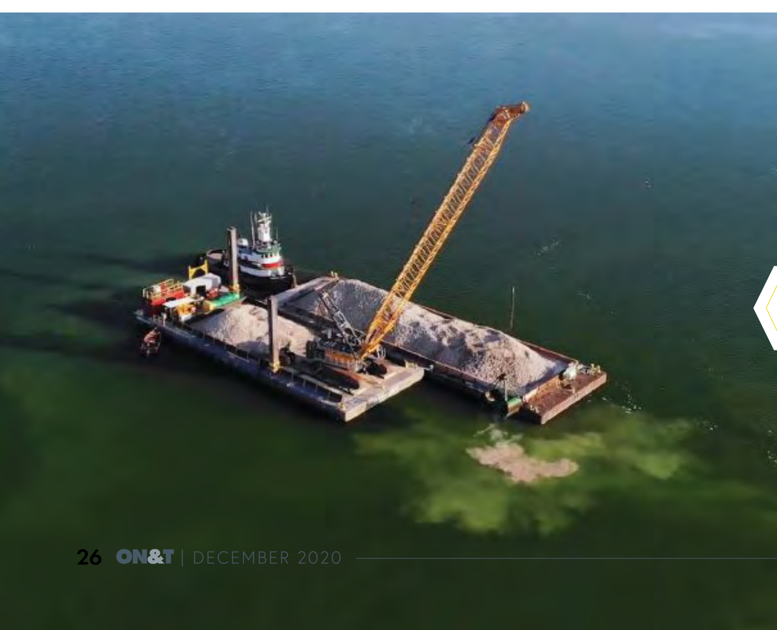
One region of such reef degradation can be found in the Great Lakes, a series of large interconnected freshwater lakes located near the Canada-United States border. Reefs here are made from glacial till and small rock formations, as opposed to coral, and provide essential habitats to support the freshwater biospehere. These reefs serve as both spawning sites and nursery grounds for a range of fish species.

Historically, Saginaw Bay's warm waters have provided optimal conditions for the fish populations of Lake Huron, including Walleye, Small mouth Bass, and Suckers during the spring and Lake Whitefish, Cisco, Lake Trout, and Burbot in the fall. Over time, human development has compromised these waters. Centuries of logging, agriculture and heavy industrial development have released significant run-off into the Saginaw Bay watershed, contaminating deposits that have progressively destroyed much of the native fish population and the natural rock reefs. More specifically, the loss of inner Saginaw Bay's rock reefs contributed to the 1940s collapse of Saginaw Bay's Walleye fishery and negatively impacted local populations of Lake Whitefish, Lake Trout, and Burbot.

COREYON REEF RESTORATION

The recovery of damaged reefs like these is dependent on a comprehensive restoration strategy, one that guarantees multi-tiered stakeholder engagement and policy commitment. It is also contingent on regional initiatives to identify local challenges and establish measures to monitor and intervene with meaningful action. The results of a multi-year assessment found that conditions in the inner bay were suitable for restoration, with the Coreyon Reef identified as a priority restoration site.

With financial support from the Environmental Protection Agency and Saginaw Bay Watershed Initiative Network, the collaborative reef restoration team began moving forward with the design, permitting, construction, and restoration of the Coreyon Reef. The ongoing purpose of the rock reef restoration project is to restore



» *Restoration of Coreyon Reef, Inner Saginaw Bay, began in early 2019 and was completed by the fall of 2019. (Photo credit: JW Fishers)*

off-shore rock reef spawning habitats that benefit Walleye, Lake Whitefish, and Lake Trout, to name but a few.

The project was approved and funded by a Great Lakes Restoration Initiative (GLRI) grant of $980,000 and a grant of $25,000 from Saginaw Bay Watershed Initiative Network (Saginaw Bay WIN). With a budget just north of $1 million, the project relied on collaboration between a number of key partners, including the Michigan Department of Natural Resources (Michigan DNR) Fisheries Division and the Michigan Environmental and Great Lakes & Energy Department (Michigan EGLE) Remediation Division.

» *Restoration of Coreyon Reef, Inner Saginaw Bay, began in early 2019 and was completed by the fall of 2019. (Photo credit: JW Fishers)*

Construction began in early 2019 and was completed by the fall of 2019, resulting in the restoration of two acres of reef habitat. This complex process was carefully documented and culminated in a film that profiles the initial post-construction examination work. The documentary premiered at the Thunder Bay International Film Festival in January 2020.

Dr. David Fielder's team (Michigan DNR) was a major contributor to the project, and the ongoing work by Michigan DNR will be central to the long-term evaluation of the relative attractiveness of the new reef to different fish species. The new reef was restored with two different types or rock (one acre of each), so the differences in productivity can be measured. Michigan DNR is partnering with Purdue University on the post-construction evaluation of the reef.

» *High performance ROVs like the SeaLion-2 ROV are instrumental to the documentation of reef restoration best practice. (Photo credit: JW Fishers)*

THE ROLE OF OCEAN TECH

Emerging technologies will continue to play a key role in the pre-, mid-, and post-processing of reef restoration projects like these. JW Fishers' Sealion-2 Remote Operated Vehicle (ROV) was selected for the Coreyon Reef; The ROV was used as a visual aid to ensure that the rocks were placed correctly, and it was also used to monitor the new reef's activity. Dr. Fielder stated: "We did also use our JW Fishers' SSS-dual frequency side scan sonar for additional assessment but unfortunately the filming didn't capture that. On the whole, JW Fishers' equipment played a central role in that habitat work. We will be going back out there at 'ice out' to take another look (with hopefully better visibility)." Ice out, as Dr. Fielder mentioned, is when the Spring thaw allows for sufficient melting to continue operations.

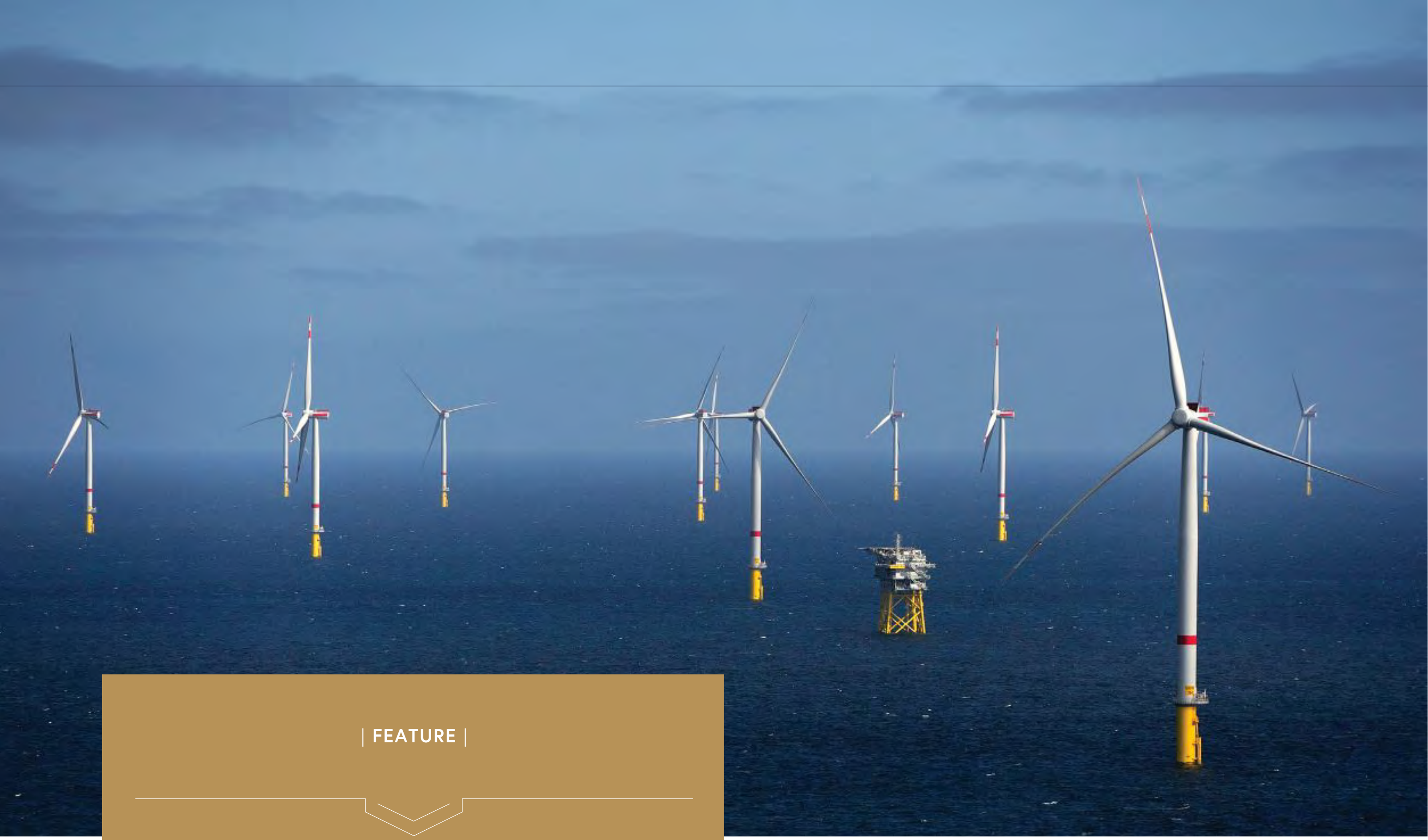
» *The SeaLion-2 ROV was used as a visual aid to ensure that the rocks were placed correctly, and it was also used to monitor the new reef's activity. (Photo credit: JW Fishers)*

In most of the onboard footage of the documentary, Dr. Fielder is operating the Sealion-2 ROV. The team member operating the boat is Captain Bill Wellenkamp and the technician launching the ROV is Darren Vercnocke. There was more good news for Dr. Fielder and his team in 2019 with another $1 million awarded for further reef work in Saginaw Bay, and JW Fishers is proud to be part of the response team!

It is clear that the future of our global waters relies on reef restoration initiatives like this. The ongoing evaluation of this demonstration project will no doubt inform future reef restoration plans throughout the Great Lakes and beyond. Following the initial restoration, this will require the clear documentation of progress and timely intervention. High performance ROVs like the Sealion-2, equipped with top-of-the-line front and rear facing color cameras with pan and tilt, as well as two powerful 2200 lumen LED lights for illumination, will prove instrumental to the documentation of best practices and for engagement with key stakeholders.

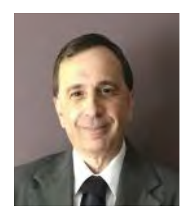
The feature length documentary can be found at: *https://www.conservationfund.org/videos/408-water/2176-coreyon*

For more information about JW Fishers' products, visit: *www.jwfishers.com*



| FEATURE |

THE FUTURE OF **HYDROGEN AS A MARKET FOR SUBMARINE CABLES**



By John Manock,
Editor, SubCableWorld

» *Ørsted offshore wind farm in the North Sea. (Photo credit: Ørsted/ Matthias Ibeler)*

In the submarine cable market, the last decade has been full of pleasant surprises. On the telecommunications side, construction of new submarine fiber optic cables has surged dramatically after years of stagnation. New markets have opened up, with cables no longer being routed between major economic and population centers, but between huge data centers or connecting some of the smallest and most remote islands on Earth.

On the submarine power cable side, the interconnector market has taken off. New technologies are allowing the transmission of vast amounts of electricity over distances not dreamed of 20 years ago. Interconnectors also are being built out to small islands around the world, providing them a steady power supply that is often cleaner than the dirty fuels previously used.

In the offshore wind cable market, the market has expanded geographically outside of its traditional space of the North Sea. In Europe, plans are progressing for offshore wind farms in virtually every body of salt water that can be reached. In Asia, Taiwan has emerged as a major market and, very quietly, Vietnam has tremendous potential and saw its first offshore wind cable supply contract award earlier this year. The USA continues to have great promise and President-elect Biden's clean energy plan calls for strong investment in offshore wind.

The potential size of the market already is enormous. RenewableUK forecasts that more than 15,000 kilometers of offshore wind cable could be needed between 2020 and 2024 to meet demand. SubCableWorld has forecasted a U.S. market of between 9,000 and 14,000 kilometers of cable contracted for by 2030.

But as large as the global potential for offshore wind is, offshore wind cable is used for only one application, bringing the electricity generated by the wind farm to the mainland grid. The market can only expand geographically because it has a single application. Well, not quite.

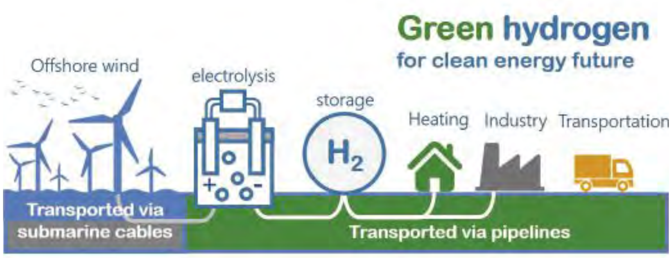
HYDROGEN-AS-A-FUEL

One of the interesting developments in the fight against climate change has been the amount of innovation that is taking place to find a solution. Technologies that were in their infancy only 20 years ago have become commonplace. Other technologies, some old and some new, have gained a momentum that until recently would have never been imaging. And some, often unexpectedly, provide a rich potential market for offshore wind cables.

One of these old/new technologies that does just this involves hydrogen. The simplest of all the elements with only one proton

and one electron, hydrogen makes an amazing fuel in that it burns completely clean. In a nod to the telecom industry, where everything needs to have an acronym and [fill in the blank]-as-a-service (xAAS) is the most popular one, we will call this hydrogen-as-a-fuel (HAAF).

The history of HAAF goes back decades. In the 1970s, in response to gasoline shortages, there were serious efforts to build hydrogen motors for automobiles. While these did not go far, technological advances and the need to cut carbon emissions in this century have given HAAF a new momentum.



» *How "green" hydrogen production works.*

SCALING UP

Given the current situation regarding climate change, HAAF had one big problem. To produce hydrogen in the quantities needed to use as a fuel, you need to electrolyze water; breaking it up into hydrogen and oxygen. This requires a lot of electricity. If you're using fossil fuels to generate electricity to produce hydrogen to replace fossil fuels in automobiles, then you're not really making progress.

The solution to this is to use clean energy for the electrolysis to produce the hydrogen and the offshore wind industry is stepping forward to make this happen.

In Europe, several projects are under development that would use offshore-wind-generated electricity to power hydrogen production activities. What is interesting about these projects is that all of the electricity generated at these wind farms will go directly to the hydrogen manufacturing facilities rather than to the power grid. This makes the production of hydrogen, as well as the use of it as a fuel, completely clean. This is often called "clean" or "green" hydrogen.

Two HAAF production projects using offshore wind and involving Ørsted, the Danish energy company and the world's leader in offshore wind deployment, are underway in Europe. One, announced in August 2020, sees partners Copenhagen Airports, A.P. Moller - Maersk, DSV Panalpina, DFDS, SAS and Ørsted developing an industrial-scale production facility to produce sustainable hydrogen fuels for road, maritime and air transport in the Copenhagen area and powered by offshore wind. A second, smaller-scale project was announced in November and has Ørsted and BP partnering. Ørsted will provide offshore-wind-generated power to a BP refinery in Germany to produce hydrogen that will be used at the refinery. Of course, all of these new wind farms serving the hydrogen-production industry will require offshore wind cables to collect the electricity and bring it to shore.

A NEW ERA FOR THE USA?

One has to wonder about the potential for offshore-wind-generated power for hydrogen production in the US market, which lags far behind Europe in this area. Again, the President-elect's energy plan highlights investment in HAAF. How might this play out? Some of the smaller states, which happen to be among the leaders in offshore wind as a way to meet their renewable energy goals, may soon have all the offshore wind power they need. Take Rhode Island, for example. It was the first state to build an offshore wind farm (30MW), has plans for a 400MW farm (Revolution Wind) and recently announced plans for another 600MW procurement. The state also has the most ambitious energy goal in the country of 100% renewables by 2030. The offshore wind farms and onshore renewable sources are on track to bring the total to 82% of the state's energy usage by 2030.

So, would Rhode Island need any more offshore wind after 2030? Perhaps not, or at least not much. But while Rhode Island is small, it has huge offshore wind resources. After 2030, might HAAF be a way to utilize these resources for a state that may not need additional offshore-wind-generated electricity for its grid anymore? And might other states follow the same path as they near their renewable energy goals in the post-2030 world.

This, of course, remains to be seen, but it is a very plausible scenario. At some point, hydrogen production powered by offshore wind will come to the US. In terms of the cable market, this demonstrates that new applications for submarine cables continue to show themselves in totally unexpected ways thanks to the innovation and outside-of-the-box thinking of the people in these developing industries. And the future for submarine cables is all the brighter because of this.

For more information, visit *www.subcableworld.com.*

| FEATURE |

THE FUTURE OF OCEAN LISTENING

By Mark Wood, *President, Ocean Sonics*

» *Ocean Sonics' SC60 hydrophone processes data while streaming HD acoustic data in real time. With a titanium casing, the SC60 is 6,000 m depth rated and so perfect for deep water deployment. (Photo credit: Ocean Sonics)*

Listening. It is what we do, it is our guiding principle, and it is what has made Ocean Sonics a trusted word leader in ocean listening. Since Ocean Sonics began producing underwater acoustic data solutions in 2012, we have listened to acoustic experts, industry partners and users of ocean sound data. We have listened to every compliment and congratulations, but we have listened even closer to every complaint, every frustration, and every failure.

Overcoming failure and challenging the status quo is what makes Ocean Sonics different. We choose to turn challenges into opportunities. Just because something has always been done a certain way does not mean that is the way it must be done forever. We choose to be unconventional and ask ourselves the hard questions, including the ones that sound impossible and that others prefer to avoid.

- *"How do we build a sensor to deploy at the deepest points of the ocean?"*
- *"What if we didn't have to wait for processed data?"*
- *"Why do we record, what if we could listen instead?"*
- *"What if we could answer simple questions in real time, like, 'is there a leak?'"*

By never settling for what is easy and what is proven, Ocean Sonics dedicated itself to developing game-changing ocean technology, creating the world's first digital, real-time underwater listening device.

REAL-TIME SIMPLICITY

The icListen made ocean sound data more accessible. Users no longer had to be acoustics experts to view and interpret acoustic data. Processed at the source, data was available and ready to use to allow for simplified decision making. By listening instead of recording, Ocean Sonics has been able to provide instant answers to important questions, resulting in improved environmental practices for industrial activities and protection for the oceans most vulnerable and at-risk species. There is a joy in the simplicity of an icListen. While it is an innovative tool, with years of prototyping, engineering, testing behind it, it is uncomplicated in its use. For even the most novice of users, an icListen opens up the world of ocean sound, immediately and without fuss.

At Ocean Sonics we share. We share data and access, but we also share ideas. Our team is allowed to dream and run with ideas. We seek out partnerships and projects that test us. We are not afraid to confront our limits and push past them. Why stop at 3,500 m when we can reach depths unexplored. Our culture of sharing has led to numerous innovations and improvements to our products and to how we support those collecting ocean sounds data. Without the freedom to share ideas, we never would have developed the launch box, a wireless solution for hydrophone deployments when access to power and internet or cell connections are not readily available.

CHALLENGING INNOVATION

Our unique company culture reminds us to stay humble. We choose to learn. As we share ideas and explore opportunities, we are reminded that while not every venture is a grand success, every venture is an opportunity to learn. We develop and test new methods and approaches to existing ideas. We

» The SC60 allows operators to collect ocean sound data accurately, easily and with confidence, with ultra low-noise and wide dynamic range for high-quality signal quality and stability. Ocean Sonics' In-line Hydrophone Frame helps safeguard underwater moorings. (Photo credit: Ocean Sonics)

» The new architecture of the icListen Kayak has simplified arrays; With the new Universal Hydrophone Bus, or UHB, users can now string up to 100 hydrophones on a single cable, making it easy to design and deploy, large scalable arrays. (Photo credit: Ocean Sonics)

» The RB9 hydrophone is 900 m depth rated and outfitted with Teledyne Reson sensor tips. (Photo credit: Ocean Sonics)

» Ocean Sonics offers a range of accessories and deployment products, such as launch boxes to make your Smart Hydrophone completely wireless. (Photo credit: Ocean Sonics)

approach problems with a broad, holistic view and we stay curious. Without asking ourselves the difficult questions, such as, *why are acoustic arrays so difficult and how can we make them easier for people to use?* the newest icListen, the icListen Kayak, would not exist.

Creating a new hydrophone architecture was a risk. We know that change occurs when risks are taken, we make space for failure and use it as a chance to learn. The original icListen Smart Hydrophone was a game changer in its own right, but we choose to look ahead. We listened to the researchers, companies and organizations working with ocean sound data. We heard their frustrations and complaints, and we heard what they really wanted and what they wished they could do. Coming from a place of optimism, Ocean Sonics chose to ask, what if…?

- *"What if we could deliver real-time sound data from a low power instrument?"*
- *"What if we could integrate smart sensors quickly and easily?"*
- *"What if we could scale acoustic arrays to huge sizes?"*

THE FUTURE

Looking ahead meant taking what we saw was possible with existing acoustic architecture and we imagined what could become possible. We chose to be provocative and saw opportunities instead of limitations. We started conversations by asking, *what would you like to achieve and how can we help you do that?* We turned our users' aspirations into our goals and took them on headfirst. In 2021, Ocean Sonics plans to roll out brand new underwater listening tools, ready for integration, ready to scale into huge acoustic arrays, and ready to integrate into even the most challenging platforms.

At Ocean Sonics, our goal is to be the leader in ocean listening. In working towards that goal, we have also managed to become leaders in sharing, risk taking, learning, and unconventional thinking. Listening has been at the core of what we do since we began designing and building hydrophones. We are always ready to listen, now.

For more information, visit:
www.oceansonics.com.

| FEATURE |

THE FUTURE OF OCEAN INNOVATION BEYOND 2020

By Rhonda Moniz, *Host of ON&T's Podcast, Sea State*

» *As the global maritime sector becomes more and dependent on digitalization automation and the integration of operations, cyber security threats have become all too real.*

As vexing as the last 12 months have been for professionals in the ocean community, technological progress has been a reassuring constant. The advances of ocean technology over the last two decades have had a transformative impact on the way we work in marine environments—from in-field operations to commercial endeavors—so the expectation is that this trend will continue as we set sail on a new decade of exploration.

The pandemic, unquestionably, upended many industries; 2020 has been a year of uncertainty, trepidation, and protracted frustration. However, the apparent challenges do present emerging growth opportunities in certain areas such as data and analytics, robotics, sensors and communication, carbon capture and storage, marine biotechnology, and smart shipping, to name just a few.

Further, as we see the rollout of the United Nation's Decade of Ocean Science for Sustainable Development (2021-2030), new technologies will need to strike the appropriate balance between commercial and environmental needs and comply with potentially shifting environmental policies. There is mounting pressure to curb the carbon footprint of the maritime sector, especially the shipping industry. "Greener" vessels will require more efficient propeller design, hybrid power generation, renewable sources of energy, and emissions abatement technologies.

MARINE ROBOTICS

There have also been some key developments in the marine robotics industry in recent years, which are likely to continue—at an accelerated rate—in the immediate years to come. Autonomy and unmanned systems are transforming every aspect of the way we operate at sea, from ship building to ocean exploration, and from offshore energy to maritime security.

The demand for pioneering engineers, equipped to design, fabricate, and deliver autonomous systems capable of incorporating sharper sensor technology, enhanced battery capacity, and intuitive interoperability, will be on well-positioned to serve a range of industries and markets looking to leverage AI and Machine Learning in the name of operational efficiency and heightened safety.

More specifically, manufacturers of autonomous vehicles—Autonomous/Unmanned Surface Vehicles (ASVs/USVs) and Autonomous Underwater Vehicles (AUVs)—are likely to see increasing demand from both public and private interests as they look to capitalize on the advent of remote, uncrewed operations.

» *SeaRobotics' SR-Endurance 7.0; multi-mission ASVs will become instrumental for defense and scientific applications. (Photo credit: SeaRobotics)*

These uncrewed systems will, in turn, place increased emphasis on the need for—and ongoing investment in—a comprehensive IT and communications infrastructure to facilitate the accurate retrieval and processing of vast swathes of data, in real-time. Where once we were left wanting for meaningful knowledge about the ocean, our present-day challenge is how to process and manage an unprecedented surge of information.

A WEALTH OF DATA

The need to store and archive data, either onshore or onboard a vessel or offshore platform, will ramp up the need for continuing IT investments. Cognitive systems will act as data interpreters for operators and the ability to transmit information safely will prove essential. The effort to attain efficient data transfer and the use of wireless communications has been the adopted method to date; WiFi, satellites, and Very High Frequency (VHF) have been standard forms for communication. The new generation of 5G, more advanced satellite constellations, and WiFi will continue to strengthen this communication infrastructure, while increasing maritime safety and supporting ever more stringent asset management. 5G technology will further facilitate the use of smart drones for asset and vessel management, real-time monitoring, and the use of IoT sensors.

MARITIME SECURITY

There is also the growing need to enhance maritime security beyond 2020. The threats are extensive, and include piracy, trafficking of narcotics, people and illegal goods, terrorism, illegal fishing, maritime accidents and disasters, or crimes against the environment.

» *iXblue's multi-purpose USV. (Photo credit: iXblue)*

As the global maritime sector becomes more and more dependent on digitalization, automation and the integration of operations, cyber security threats have become all too real and are on the rise. There have already been several documented examples of how a vessel's GPS can be manipulated remotely, making the maritime trade system increasingly sensitive to attack. As autonomy becomes more widely adopted, so will the need to protect those networks and the operational technology associated with them.

These have indeed been challenging times, dogged by uncertainty, but the critical role of ocean technology—both during and beyond the pandemic—remains undisputed.

» *Deploying the Deep Trekker REVOLUTION. (Photo credit: Deep Trekker)*

THE FUTURE OF **AUTONOMOUS SUBMERSIBLES**

By Sam Macdonald, *President, Deep Trekker*

Autonomous vehicles are truly the future of submersible vehicles. These unmanned, self-controlled robots provide the ocean industries with a safe, reliable and advanced tool for underwater work and exploration.

Equipped with HD cameras, remote sensors and innovative tools and other add-ons, autonomous unmanned vehicles (AUVs) are changing the landscape of subsea industries. Long, costly or otherwise challenging missions benefit the most from the use of an AUV. Take for instance a search and recovery operation following an airplane crash over an ocean or extensive hydrographic surveys needed for infrastructure construction. Deploying an AUV in such situations provides operators with a valuable tool that allows for accurate results, even in remote, hazardous and vastly expansive environments. The vehicle's ability to operate autonomously—independent of a host vessel—allows for a revolutionary approach to underwater solutions.

Some might argue that perhaps the development of AUV technology has lagged in recent years, but AUVs face tough challenges that are unique to any underwater environment. The primary hurdle AUVs must overcome is underwater communication and navigation. Common topside communications, such as radio, are unable to be used in subsea conditions as the electromagnetic waves that they rely on are unable to travel effectively in the water. The harshness of underwater environments—including multipath interference and shadow zones—further compound communication and navigation complications. Acoustic waves, however, provide operators with an effective and reliable manner in which to communicate below the water line. It is from acoustic technologies that AUVs are able to function accurately.

» *The controller of the Deep Trekker REVOLUTION. (Photo credit: Deep Trekker)*

OPTIMIZING OPERATIONS

ROVs alone offer operators numerous opportunities to optimize their operations. The ease of using an ROV for underwater or submerged infrastructure inspections allows for convenient and frequent and ongoing asset integrity management, helping operators catch minor issues before they become costly failures. Furthermore, an ROV can be deployed without taking systems offline or draining assets. Quick deployment and minimal personnel requirements allow for the optimization of both time and available budgets. From shipping to infrastructure to aquaculture to energy production, the time and money saved by using an ROV for underwater tasks is significant. Finally, and perhaps most importantly, ROVs help keep human divers safe and out of potentially dangerous situations.

AUVs can further expand on these operational benefits. The ease in which inspections can take place with an AUV will allow for frequent and extensive inspections to ensure safe and efficient submerged infrastructure. Smaller teams can tackle the job, freeing up employees for alternative tasks. Finally, human divers can be kept safe and out of risky situations.

TRANSFORMATIVE IMPACT

Operators can take advantage of the advanced innovation of AUVs in numerous ways to optimize their operations to ensure best use of resources. Maps of the seafloor can be generated using an AUV

prior to the construction of subsea infrastructure to ensure that design and construction is as efficient and effective as possible. Structures such as pipelines can be installed cost effectively and with minimal environmental disruption with the strategic use of AUVs. Surveys can be conducted with AUVs where previous methods would be unsafe or too expensive. Inspections can be done with minimal disruption to workflow. From a more scientific perspective, AUVs can gather a wide range of relevant data over great distances or extended periods of time without monopolizing a team of researchers.

The possibilities of an AUV are endless and with strategic planning can be used to generate optimal results within an organization. The transformative impact of autonomous underwater vehicles on marine industries has the potential to be tremendous as the adoption of such technology becomes commonplace. The extensive range of AUVs in existence is sure to continue to grow, offering vehicles from tens to thousands of kilograms in weight. With continued use, industries can expect quick and thorough results with minimal time, personnel and budgetary requirements.

A SUBMERSIBLE REVOLUTION

As increasing adoption of AUVs leads to further investment in AUV technology, vehicles are certain to become more advanced and offer even further benefits to users. The evolution of AUV technology has and will continue to rapidly evolve as new vehicles, technologies and applications grow.

Taking a big step towards developing a hybrid autonomous vehicle, submersible robotics company Deep Trekker released a new ROV package, the REVOLUTION NAV. Building off of the REVOLUTION ROV, the NAV offers advanced navigation and stabilization, leading the way in semi-autonomous vehicles. The REVOLUTION NAV package tackles underwater navigation by providing pilots with a Google map showing their ROV's position on screen, allowing users to see where they are, leave a trail to show where they have been and set points of interest to where they want to return to. Furthermore, advanced stabilization features allow operators to

» The Deep Trekker REVOLUTION ready for deployment. (Photo credit: Deep Trekker)

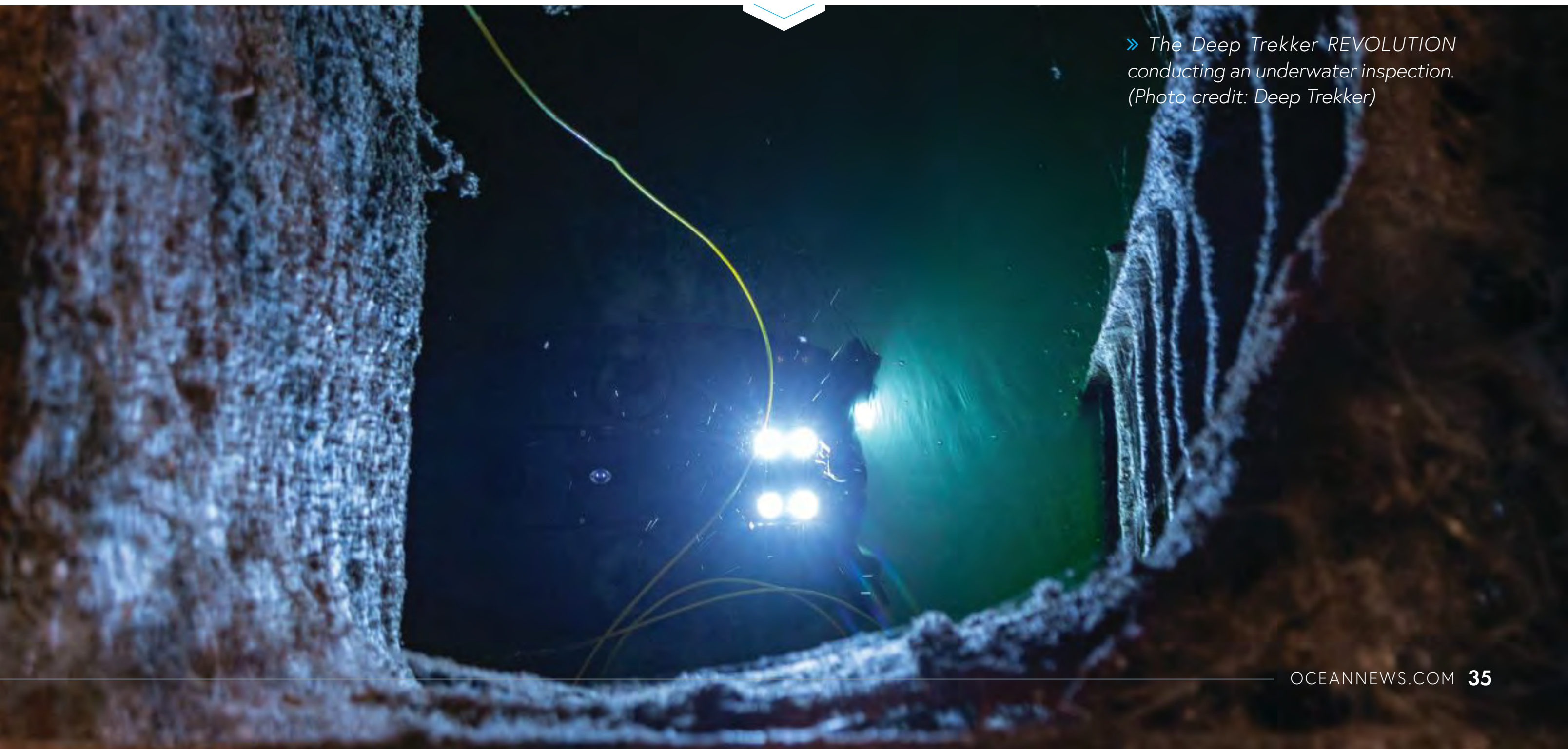
station hold against currents, enable auto altitude, and pilot their vehicle precisely and accurately through varying water conditions.

The REVOLUTION NAV's capabilities are especially useful for applications in open, murky water or when there is significant current. The state-of-the-art features provide benefits across numerous applications for missions requiring precise navigation, location tracking and reporting. Search and recovery teams, for example, will be able to easily see and track what areas have been covered as part of the search.

The pairing of USBL and DVL with Deep Trekker's BRIDGE technology and sensor fusion brings this intelligent navigation system to life. USBL systems utilize sonar beacons to triangulate the position of the ROV. A GPS chip inside the Deep Trekker BRIDGE Controller allows the system to correlate the data and provide real time latitude and longitude. DVL offers users an enhanced navigational system by providing pilots with the ability to accurately and conveniently determine velocity relative to the seafloor, allowing for easy navigation through the most complex of operations.

The team at Deep Trekker looks forward to continued innovation and growth as the landscape of underwater technology evolves and expands.

For more information, visit: *www.deeptrekker.com.*



» The Deep Trekker REVOLUTION conducting an underwater inspection. (Photo credit: Deep Trekker)

THE FUTURE OF SEABED DATA, MAPPING, AND INTELLIGENCE

By Gail Clark
Managing Director, OceanIQ, Global Marine Group

As seabed usage across multiple industries increases, having an accurate understanding of the seafloor to plan for future installations, and protect those in existence, has become essential. There are currently already 1,450,000 km of subsea telecoms cable in commission, and power cables kilometers are surging exponentially thanks to the boom in offshore renewables and the growing need for power links, with an estimated 20,000 km installed in northern European waters alone by 2030.

MEETING DEMAND FOR CONNECTIVITY

Throughout 2020, internet usage has spiked dramatically with global web traffic increasing by 30% in March coinciding with the introduction of nationwide lockdowns in response to the COVID-19 pandemic. The beginnings of a second wave of infections in many countries worldwide will have broad implications on internet usage, particularly for online retailers with e-commerce sales predicted to grow by 25-35%, thus creating a greater demand on internet service providers.

» *Subsea cable routes as featured in OceanIQ's industry-leading GeoCable® GIS. (Image credit: OceanIQ)*

Before COVID-19 really took hold in the UK, the London Internet Exchange, which tracks and monitors internet transmissions throughout the country, showed a weekly peak of 3.86 Tbps. By comparison, at the end of the 27th March—the second full week of the first UK COVID-19 lockdown—the exchange recorded peak traffic at 4.52 Tbps; a picture replicated right across the world. The story is similar for various internet providers across the country. Vodafone, which serves 18 million customers in the UK, reported that data usage had also spiked by 30% during the period of lockdown. In some European countries, usage had gone up by nearly 50%, as more and more people relied on the internet to work, relax, and communicate with others. Virgin Media, which has over five million customers, also reported increases in data use as the crisis increased in intensity and reported in June 2020 that their customers had downloaded an extra 325 GB of data per household during the first nationwide lockdown. Early reports were also indicating that Virgin Media's network was only displaying a small decline in data usage once lockdown measures had been eased, suggesting a new normal for increased data usage would continue into the latter half of the year.

To continue to meet this seemingly insatiable appetite for connectivity globally, the subsea cable infrastructure needs to grow, flex, and remain secure to deliver a consistent supply around the clock.

LONG-TERM PLANNING

OceanIQ's database of subsea cable faults is an invaluable resource containing information on over 5,500 historical cable faults, approximately 95% of all faults worldwide. The database shows an average of 190 annual faults on fiber optic cables over the last five years, which is rising approximately 10% per year. To ensure an asset's integrity over its lifespan, the creation of a fully informed mitigation strategy is required. The strategy must consider the risks faced by new cable routes when compared to historic faults already encountered within existing or decommissioned networks located in close proximity to the proposed route.

In order to help curb the upward fault trend for new cable route projects,

preparation is key. Interpreting a wealth of data from simple facts and figures and into meaningful intelligence enables customers to make informed decisions to establish the best and safest cable route that maximizes installation efficiency and minimizes risk to assets.

TRANSFORMING DATA INTO INTELLIGENCE

The amount of information available from online sources is always increasing and the technology for acquiring more accurate and plentiful data and mapping during cable route survey and planning is advancing continually. With those two factors at play, route engineers working in the planning and preparation phases of cable installations will have to become ever more skillful in working with and interpreting this flood of data for two reasons: firstly, to fully embrace the opportunities in developing cable routes that are more secure from an earlier stage than ever before, and secondly to enable findings to be presented and route engineering decisions clearly and concisely articulated to clients and other interested parties, filtering out the unnecessary information to reach only that of value for cable owners.

OceanIQ, the fourth business unit in Global Marine Group's subsea engineering portfolio, is well positioned to do just that thanks to both their experience in working with large datasets such as the businesses very own cable database, with records management holding information on over 150,000 kms of in-service cable systems, as well as their industry-leading GeoCable® GIS software, which gives the team an intrinsic understanding of the seabed. The GeoCable® software comprises information on over 2.6 million kms of as-laid cable around the globe, combining multiple layers of intelligence with route planning functionality in a comprehensive software package that can confidently manage and analyze customized project requirements when utilized by skilled route engineers. With an unparalleled record of 97% of all fiber optic cables laid worldwide, and a substantial amount of power cables, OceanIQ's understanding of the ocean floor is unique and extensive.

INNOVATING FOR THE FUTURE

Almost 66% of the world's population is expected to have access to the internet by 2023 according to Cisco white paper, with three times as many internet-enabled devices in operation than the human population. Demands for increased bandwidth to accommodate for the world's evolving technologies and devices will put pressure on aging cable systems and require investment in the submarine cables market in response, with financial investment projected to rise to a near US$21 billion by 2023 according to Research and Markets. Consideration of how to increase data transmission speeds and how to safely install these high-capacity cables within the world's oceans will be of great concern for installation and maintenance companies in the next decade.

The evolution of technology also provides the ability to acquire and make use of increased datasets that can help provide a better picture of the conditions faced by new subsea cable projects installed worldwide. The acquisition, monitoring, and interpretation of this data is fundamental to ensuring economic viability and operational feasibility of the networks which will serve the data needs of future populations.

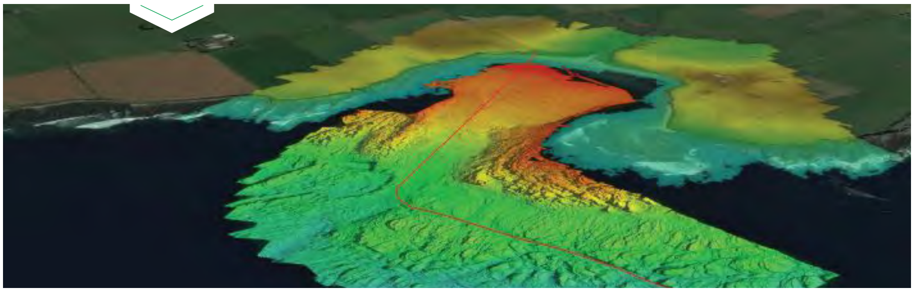
OCEANIQ: DECADES OF FIRST-HAND EXPERIENCE

OceanIQ delivers industry-leading subsea cable data, survey, route engineering and consultancy services for telecom and power cable route planning projects. The highly experienced team also work to maximize the lifespan and efficiency of live systems across the globe. The business is built upon an existing wealth of data and knowledge acquired through years of cable installation and maintenance projects undertaken in support of sister companies Global Marine and Global Offshore, and one that continues to grow with each completed project.

For more information, visit:
www.oceaniq.co.uk
www.globalmarine.group

» A beach cable pull carried out by Global Offshore's Normand Clipper—a specialist cable installation vessel. (Photo credit: OceanIQ)

» Matressing can be utilized as a solution for cable faults identified by a Cable Protection Assessment (CPA). (Photo credit: OceanIQ)



» Marine survey and bathymetry data are fundamental route engineering tools in cable system planning. (Image credit: OceanIQ)

THE FUTURE OF AUTONOMOUS REMOTE SURVEY SERVICES

By Rob Collaro,
Director - Hydrographic Business Unit, Morgan & Eklund, Inc.

When it comes to hydrographic survey, there is a clear paradox between the highly sophisticated and increasingly accurate instrumentation used to capture data and the means by which these assets are deployed and managed in the field. While recent advances in sensor technology have ushered in a new line of sonar and positioning equipment, the topside process of collecting data is an arduous and time-consuming task. But there are signs that breakthroughs in unmanned systems for commercial use are beginning to rewrite the marine survey playbook.

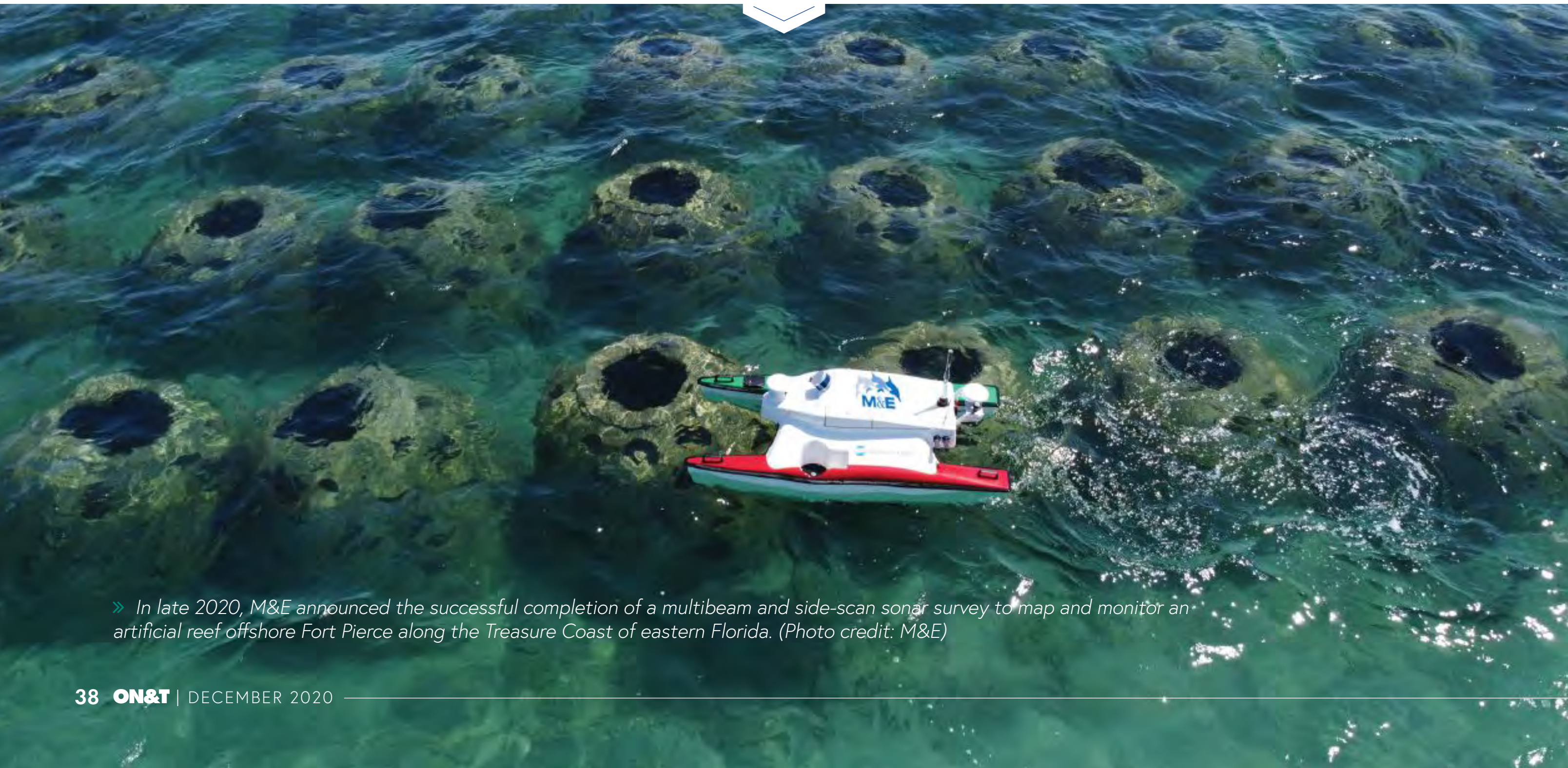
Today, a hydrographer's toolkit—specialized instrumentation, such as multibeam echo sounders, side scan sonar, LiDAR, and RTK GPS—can be incorporated into autonomous platforms that are perfectly suited to running repetitive survey lines and standard sampling. These Autonomous Surface Vehicles (ASVs) are able to house a sensor suite that simultaneously measures the depth and size of a body of water, map its physical characteristics, and identify unique attributes or obstructions.

Market reports published in 2020 point to a burgeoning commercial market for ASVs as survey companies reassess the most effective approach to executing routine marine projects with unmatched accuracy. This has certainly been our focus at Morgan & Eklund (M&E), as we look to pass on the benefits of pioneering marine robotics to our customers. Our Autonomous Marine Survey Services division, powered by a growing fleet of custom ASVs, points to a future of remotely operated marine survey.

UNPACKING THE BENEFITS OF ASV DEPLOYMENT

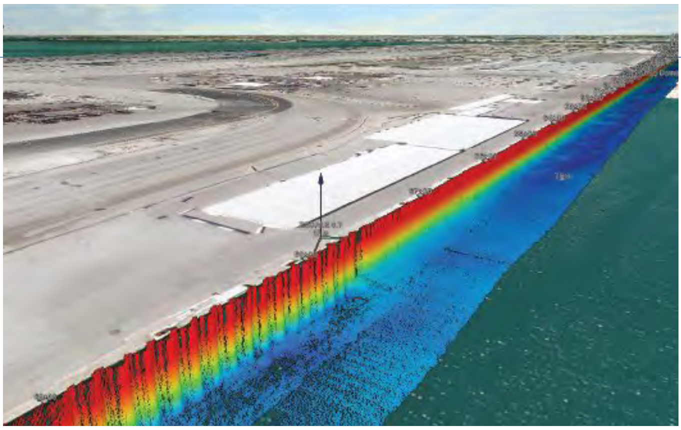
The advent of ASVs for survey operators signals a new era of efficiency and accuracy when it comes to data collection. Our goal, by investing in unmanned technology and autonomous controls, is to integrate ASVs into our day-to-day operations. Immediate advantages include:

Cost-effective field operations: The deployment of ASVs reduces the need for additional topside support, e.g. a crewed survey boat, minimalizing operational overheads and saving vessel set-up time.



» *In late 2020, M&E announced the successful completion of a multibeam and side-scan sonar survey to map and monitor an artificial reef offshore Fort Pierce along the Treasure Coast of eastern Florida. (Photo credit: M&E)*

» *The man-portability and plug-and-play capabilities of compact ASVs offer operators a key differential when it comes to survey efficiency. (Photo credit: M&E)*



» *Tightly integrated ASVs offer the perfect platform for surveying areas with limited access, such as ports, dams, tailing ponds, and other areas where typical vessel operations are limited. (Image credit: M&E)*

Precision and accuracy: The automation of monotonous survey operations removes the margin of human error and the stresses associated with manual control.

Speed of data processing and interpretation: Depending on the survey in question, data can be managed in real time from a shore-based command or workboat. The preset survey plan allows hydrographers to focus on other important aspects of operations, like survey processing and QAQC, meaning clients receive validated results sooner.

Force multiplier: Advances in autonomy mean that commanding multi-boat ASV operations in controlled environments is a means of surveying greater areas more efficiently.

SHALLOW WATER EXPERTISE

One of the ASVs central to our shallow water survey capabilities is the SR-Surveyor M1.8, from SeaRobotics' Surveyor Class of ASVs. With its catamaran hull design, the SR-Surveyor M1.8 is a unique autonomous platform equipped with a multi-sensor package, which includes an EdgeTech 2205 multibeam echosounder and Velodyne LIDAR for mapping features above the water surface. At only 1.8 meters in length, the highly-integrated system is capable of synchronized data capture, including: two frequencies of side scan, motion tolerant side scan, wide swath bathymetry, backscatter, LiDAR point cloud data, and discharge data, supported by a dual antenna RTK INS, and surface velocity sensor.

SAFETY IN MARINE ROBOTICS

ASVs remove personnel from harm's way. The SR-Surveyor M1.8's size and man-portability make it perfectly suited to surveying hard-to-access or potentially hazardous waters, as well as inspecting damaged coastal infrastructure and underwater debris fields. To this end, in recent years, M&E has deployed our fleet of ASVs on a number of high-profile projects, from the waterway survey of hurricane-torn islands to the inspection of critical offshore utility infrastructure.

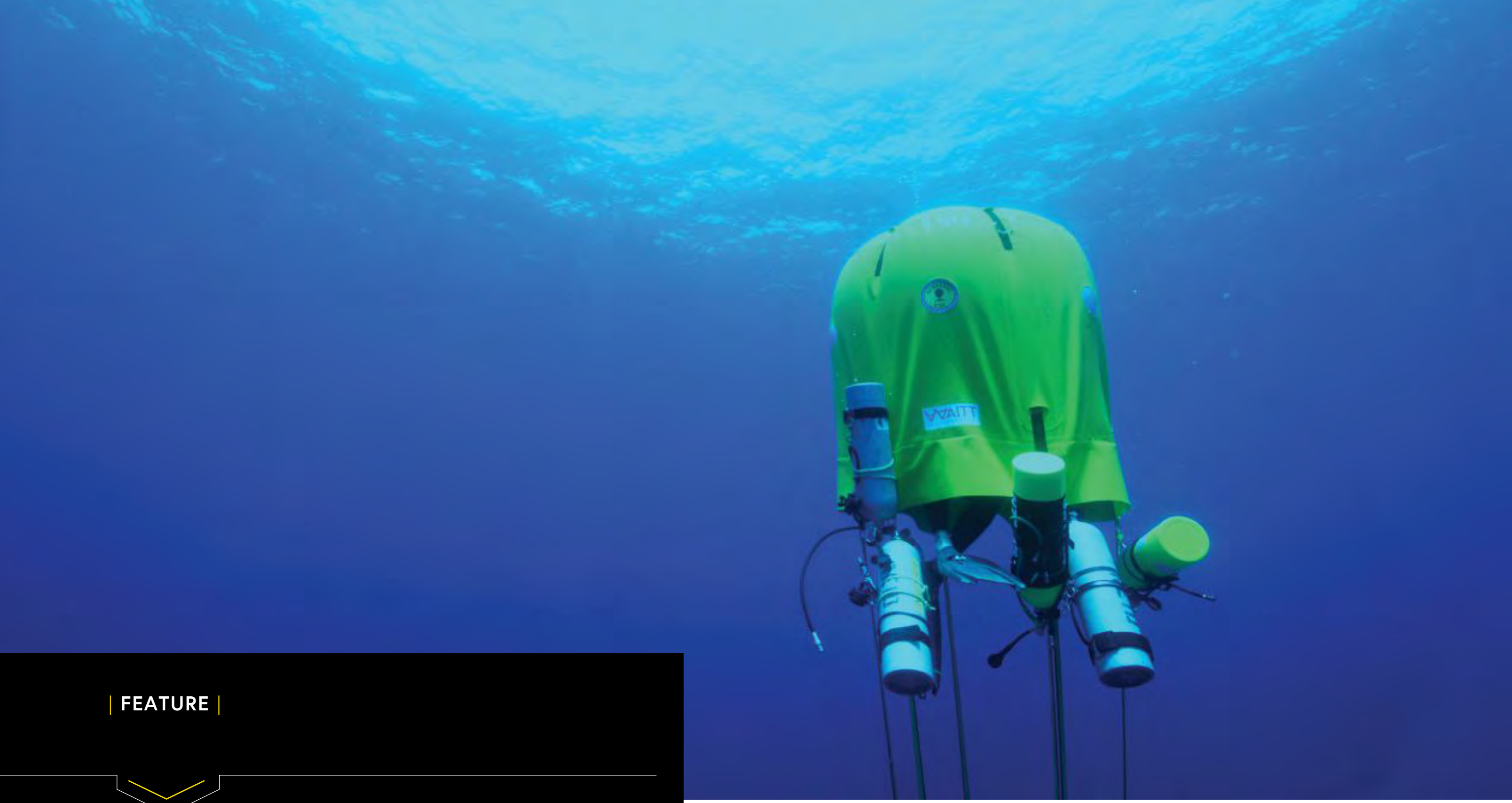
We are planning to further expand our ASV line with the purchase of a SR-Utility 3.0, a larger platform—also manufactured by SeaRobotics—which shares the same uni-cab architecture as the SR-Surveyor M1.8. This compatibility is critical for enabling plug-and-play, multi-unit deployment for a wide range of environmental, geophysical, and ocean sound survey tasks.

MAPPING THE FUTURE

M&E has continually adapted to the latest innovations and field methodologies during its 35-year history and our Autonomous Remote Survey Services division represents the latest chapter our commitment to leveraging ground-breaking technology to meet the surveying needs of intracoastal waters, beaches, and beyond by providing high quality, unbiased data to our clients.

The acquisition and subsequent integration of our ASV line is a critical part of M&E's strategy to evolve hydrographic surveying technology techniques using autonomous data acquisition, whenever possible. The implications are far reaching and will transform coastal survey services and improve the cost effectiveness, efficiency, and safety of daily operations.

To find out more about M&E's Autonomous Remote Survey Services division, visit: *www.morganeklund.com*



» *The Gen 1 Ocean Space Habitat, a portable inflatable underwater tent that puts near saturation diving excursions well within reach for technical diving. (Photo credit: M. Lombardi/National Geographic Society Waitt Grants)*

THE FUTURE **OF DIVING TECHNOLOGY**

By Michael Lombardi
Owner, Lombardi Undersea LLC

Diving is inherently technology dependent. Without it, we cannot breathe underwater, and maintaining a breathable atmosphere forms the basis for our ability to enter underwater space and use of our hands and eyes to interpret our work environment in accomplishing a task.

Many may envision pristine reefs, warm tropical breezes, and refreshing cocktails when thinking about life as a career diver. While it might be for some, mostly within the recreational or sporting realm, the reality for the majority of us is a stark contrast. There is a significant community of professionals—often out of the public eye and consequently poorly understood—who spend their very full work days in the dark, both inshore and offshore, immersed in the cold, buried in mud and working with tools to conduct tasks that fill a unique niche—attending to specialized problems that simply cannot be resolved remotely or robotically. These interventions may be as mundane as welding anodes to a sheetpile bulkhead in an industrial waterfront, to as dignified as recovering a body from a sunken vessel, and everything in between. What unifies them is the need for hands, eyes, and spatial awareness to maneuver, interpret, and make critical decisions.

DIVING COMMUNITY INVESTMENT

Interestingly, diving technology (life support in particular) hasn't changed much over the years. Equipment has evolved around the premise of regulating gasses to adequate flows, pressures, and volumes with suitable life sustaining content for the given depth and duration. Then there are added elements for safety and comfort—the ability to verbally communicate, stay warm, and better manage the physiological stress of decompression. The ever-present challenge is how to improve human performance, and this means incremental progress through demonstrated needs to address the many human factors at play within the pursuit of increased depths and/or for longer durations. While diving innovation is exciting, perhaps the most important consideration when implementing new technology is the required level of investment needed in ongoing training, maintaining proficiency, and ensuring a state of community readiness for the unique challenges that lie ahead.

Progress in advancing diving technology today is coming from divergent community sectors, each striving to address their own particular requirements. For example, the sport diving community has significantly advanced closed circuit rebreather technology in the last 20 years,

but this powerful tool is not yet routinely employed within occupational diving fields. Similarly, the offshore community has advanced saturation diving techniques to be highly mobile and not constrained to any specific geographical location, but they aren't employed for the advancement of science, leaving scientific diving tied to very short and shallow dive excursions, with deep access limited to robotic intervention. And then again, there is the public safety community who has evolved lightweight surface-air equipment and associated techniques that could significantly advance other inshore shallow-water sectors if more widely adopted.

TECHNOLOGY CONVERGENCE IS KEY

While technology is evolving in these and other distinct industry sectors, there lacks clear opportunities for the convergence of innovative technologies and techniques given regulatory inefficiencies—both real and perceived. Across the diving community, this results in a quick-to-dismiss culture that hinders the openness to embrace new technology from other sectors. A willingness to engage in cross-sector collaboration and knowledge transfer would provide the impetus for significant diving technology advancement, and benefit us all.

In my own work, I've endeavored to bridge some of these gaps, albeit at small scale, and the results, have shed light on what the future of diving technology may look like. One recent experiment was our development of a shallow water rebreather apparatus and its application to local shellfish harvesting—a technology we often mislabel for deep diving proved to increase daily harvest yields by 20%. Similarly, we applied basic principles of atmospheric management from confined space intervention and saturation diving to put to work portable inflatable habitats for scientific exploration—when coupled with generally accepted deep technical diving, these temporary shelters make it reasonable to spend a full productive work day or more underwater and all without the massive expense of permanent underwater habitats.

With just a very little innovation, we effectively put near-saturation diving excursions within reach for the enthusiast seeking an experience beyond today's conventions. And then there is the value and utility of simply thinking through these types of challenges on a routine basis—having made important investments in life systems integration and associated know-how over the years, we were able to quickly pivot in response to life-saving challenges arising from the COVID-19 pandemic.

SAVING LIVES

» The Subsalve Oxygen Treatment Hood is an FDA authorized device for treating respiratory distress from COVID-19. It and several supportive appurtenances resulted from a diving technology pivot at the start of the pandemic. (Photo credit: Los Medicos Bolivianos Online)

In March 2020, amid the ventilator shortage, there were a number of creative responses that stemmed from diving technology and which had a real impact in the form of both PPE and ventilator support. For my group, our response was to rapidly develop and bring to market the Subsalve Oxygen Treatment Hood for helmet non-invasive ventilation—understanding pressures, volumes, and flows coupled with appreciating how to navigate regulatory pathways (US FDA Emergency Use Authorization) similar to diving regulations presented a perfect storm, warranting our emergency response… diving technology has saved many lives.

This point illustrates the critical importance of diving technology—the culture and community of the working diver is one that has been steadfast throughout history, but also responsive. When the call comes it is more often than not one of emergency, but we're ready—ready to respond, ready to innovate, ready to meet the challenges of today and with the foresight to anticipate and invest in the challenges of tomorrow. Indeed, our own survival depends on it, and will continue so long as we can call our planet 'Blue'.

For more information, about Lombardi Undersea LLC, visit: www.oceanopportunity.com.

» The RD1 oxygen rebreather developed by Lombardi Undersea LLC. When applied to shellfish harvesting, yields were increased. (Photo credit: M. Lombardi)

FEATURE

THE FUTURE OF LOW-COST AUTONOMOUS SURVEY VEHICLES

Murray Lowery-Simpson, *Founder, In Nature Robotics Ltd.*

Hydrographic surveying has been used by people for nearly as long as sailing ships have been in existence. Until nearly one hundred years ago, the basic method remained unchanged: water depths were manually measured from a boat using lead lines and/or sounding poles, both of which required heaving over the side of the ship and manually recording a distance when the weighted line or pole struck the bottom, while triangulating the position of the boat with known landmarks and a sextant.

The process was time consuming and laborious, which put a practical limit on the number of depth readings that could be taken. The 20th century saw a number of improvements in surveying methods, including wire-drag surveying, echosounders, sidescan sonar and multibeam sonar. The final years of the 20th century and the first 20 of our current one, have seen significant improvements in boat positioning (using GNSS / GPS technologies) as well as resolution and accuracy improvements in sonar technology and computer processing of data. In recent years, human operated survey vessels have in some cases been replaced by unmanned and autonomous vehicles.

THE ADVENT OF THE ASV

The primary advantage of autonomous vehicles over manned survey boats is that they do not require a human to be actively engaged in the survey process. This typically saves time and money and increases surveyor safety. A number of companies currently offer autonomous surface vessels (ASVs) that can be equipped with modular and integrated packages for hydrographic surveying. Some of these include: SimpleUnmanned, LLC., Seafloor Systems Inc., SeaRobotics, OceanAlpha, and Unmanned Systems Technology. They offer single-beam, sidescan, and multi-beam transducer options, integrated with survey-grade differential GPS and inertial orientation sensors.

The ASVs store and, in some cases, process the data onboard the vessel. Processing generally requires the use of commercial grade surveying software such as HYPACK, NaviSuite, and Hydromagic. While these autonomous vehicles do offer cost improvements over traditional human operated survey boats, their pricing (which typically starts at about $10K) can still be a stretch for some operators, especially since the transducers, GPS equipment, software, and some other supported electronics are not always included.

» *A commercial single-beam echosounder (SBES) and a GPS evaluation kit mounted to a foam body board designed by the Department of Geodesy and Geomatics at HafenCity University (HCU) in Hamburg, Germany—an example of a low-cost multi sensor systems (MSSs) for hydrographic surveying. (Photo credit: Markus Kraft, HafenCity University Hamburg)*

For crowd-sourced bathymetry, government surveying agencies in developing countries, universities, and even hobbyist surveyors, there is an interest and market for lower-cost surveying technology. The Seabed 2030 Project of the Nippon Foundation and GEBCO aims to chart 100 % of the oceans by 2030 and intends to use crowdsourced bathymetry as an option to achieve this (Mayer et al. 2018), and the IHO (International Hydrographic Organization) Inter-Regional Coordinating Committee has established a Crowdsourced Bathymetry Working Group (CSBWG).

LOW INPUT, HIGH OUTPUT

The hardware requirements for implementing the navigation and autonomy functions on an ASV can be relatively modest. In 2015, Manda et al. presented a low-cost ASV-based system for hydrographic surveys. The total autonomy cost of the system was under $1,000. More

» *In Nature Robotics' AMOS (Aquatic Mini Observation System), an autonomous, solar-powered airboat that is intended for long-term water quality monitoring and surveying applications. (Photo credit: In Nature Robotics)*

» *A sample depth track obtained using a fish finder aboard AMOS. (In Nature Robotics)*

recent work at The Department of Geodesy and Geomatics at HafenCity University (HCU) in Hamburg, Germany has resulted in the development of low-cost multi sensor systems (MSSs) for hydrographic surveying. An initial MSS used a fish finder, GPS, and inertial measurement unit (IMU) at a cost of less than €300 for use with the OpenSeaMap project. The quality of the data was not sufficient for seafloor mapping however, and it required uploading to an external server for corrections and processing. A subsequent version used a commercial single-beam echosounder (SBES) and a GPS evaluation kit mounted to a foam body board and made use of an in-house calibration procedure and extended Kalman Filter (EKF) for the IMU to achieve greater accuracy.

A low-cost Robot Operating System (ROS) ASV developed by Louis Makiello at HCU was able to achieve typical depth repeatability results to within a few centimeters with a parts cost of less than €1,000. HCU research associate Markus Kraft says: "We have ongoing projects about low-cost developments of hydrographic survey devices that are apart from complete MSSs. In the forethought of the further importance of competitive survey devices in the field of low range costs—primarily for private usage but nonetheless for companies as well—we hope to collect more results of which precision ranges are possible to achieve while being very limited in budget."

SOLAR-POWERED AUTONOMY

At In Nature Robotics Ltd., we have developed a small, portable ASV called AMOS (Aquatic Mini Observation System). It is an autonomous, solar-powered airboat that is intended for long-term water quality monitoring and surveying applications.

The testing of its surveying capabilities to date has been relatively rudimentary; combining the NMEA 0183 depth output from a fish finder with GPS data acquired from an inexpensive receiver on the boat. However, plans are underway to achieve better positional and depth accuracy using slightly higher commercial-grade equipment.

There are many challenges associated with achieving accurate survey-grade depth readings that satisfy IHO standards. The speed of sound needs to be known for the water column being measured and depends on the temperature and salinity profiles of the column. The relative timing of GPS, sonar, and IMU data needs to be known in order to properly combine the raw data inputs. Multi-path reflections of sound waves can be problematic in areas with uneven topography. Tidal effects need to be known to properly model water depths over time. And multi-beam systems typically require a host of complex software processing algorithms to properly resolve swath data.

All these challenges demand a higher price for technology to give the best results, but there are signs that low-cost technology may soon become more widespread for general surveying use. Some GNSS vendors offer cm-level positioning accuracy at a cost of less than $1,000. And accurate SBES devices can be purchased for less than $1,000. Multibeam sonar is still relatively expensive, although some mechanical scanning sonar devices are now available at a cost only somewhat more than their SBES counterparts.

In the not-so-distant future, if current trends continue, there should be many smaller autonomous robots, carrying modest amounts of low-cost electronics, quietly doing their job to measure the depth of the water below them.

For more information, visit: *www.innaturerobotics.com*

| FEATURE |

THE FUTURE OF OFFSHORE WIND GENERATION

By Peter Brun,
Global Segment Leader for Offshore Wind, DNV GL – Energy

The world is headed towards a net-zero carbon future, characterized by a profound shift towards electrification and to electricity generation from renewable sources. While electricity is less than 20% of the energy mix today, it will more than double its share by 2050, according to DNV GL's fourth Energy Transition Outlook.

The dedicated power supply and use report forecasts that average capacity factors in the wind industry will keep increasing in all regions with significant expansion in Greater China, Europe, the Indian Subcontinent and North America.

However, it is still not enough to meet climate targets. This year's report states that while carbon emissions peaked in 2019, they will not fall sufficiently by 2050 to reach the Paris Agreement goal of 2°C global warming, let alone 1.5°C. In fact, the model estimates a rise in average global temperatures of 2.3°C above pre-industrial levels.

MEGA DRIVERS FUELING RENEWABLES GROWTH

In just a few decades, power systems in most regions will be dominated by solar and wind which will provide 24% of the world's electricity in 2030 and 62% by mid-century. From 2019 to 2050, global annual solar PV generation is predicted to grow 28-fold, reaching 18.7PWh just before mid-century. Installed wind capacity could increase ten-fold to 4.9TW for onshore, 1TW for fixed offshore, and 260GW for floating offshore wind.

» *Offshore wind contribution will continue to grow, reaching more than a quarter (28%) of total wind production by 2050. (Photo credit: Equinor)*

There are a number of mega drivers fueling the massive growth in offshore wind. Magnified climate change effects making consumers increasingly aware of the need to change towards greener energy sources, advances in technology lowering the costs of renewables, further electrification of society and local job creation from local plants will all shift the discourse around renewables and act as catalysts for their growth. Furthermore, as traditional energy systems age and the need for decommissioning increases, investors will look on renewables as an increasingly attractive financial prospect for replacing old fossil fuel systems.

Other trends examined in the report include wind farms increasingly providing services to the grid, more flexible generation and frequency response, and progressively detailed data and model-driven approaches (such as digital twins). These will ultimately optimize life management of wind projects and allow assessment and further improvement of manufacturing processes. This could potentially include innovative methods such as 3D printing for blade components.

Though wind generation is predominantly onshore today, the contribution of offshore wind will continue to grow, reaching more than a quarter (28%) of total wind production by 2050.

ADVANCES IN WIND TECHNOLOGY

Wind capacity additions should consistently exceed those of the previous decade until 2050. By then, solar and wind power will become the main providers of power generation, and in many cases also be complementary for each other in hybrid power plants where wind will deliver the main generation at night whereas solar will deliver during the day. The pace of expansion will be highest for fixed and floating offshore wind as they start from a lower base.

It is expected that advances in wind turbine technology, the economies of scale stimulating further industrialization of the industry, and

smarter technologies and operations will further reduce the levelized cost of energy (LCoE) and cut installation time, making offshore wind more and more attractive for investment.

For floating wind, this decade will see rapid progress from demonstration projects to commercial-scale deployments. This means that, by 2050, floating offshore wind projects could have 255GW of installed capacity: more than a fifth of the offshore wind market. Offshore wind will generate almost 9% of electricity globally by 2050, compared with 0.3% today. Bottom fixed offshore wind will grow well beyond 1TW installed capacity and in our forecast, we estimate with our current technology knowledge an increase to a staggering 1014GW in 2050.

As the number of projects rises, new wind regimes will be exploited and, although some may have lower average wind speeds, turbine manufacturers will continue to develop a range of models for varying wind conditions. Likewise, repowering older sites with modern, larger turbines, particularly offshore, will enable significantly improved energy production and reduced LCoE.

COLLABORATION: OFFSHORE WIND POWER HUBS

While the energy transition will drive change for power systems and grids, electricity markets will be essential enablers for the transition. Globally, the CAPEX ratio between transmission (33%) and distribution (67%) has remained almost constant over the last five years. However, in the case of the most advanced renewables integrators, the ratio starts to shift towards transmission.

Investment in transmission infrastructure will increase further when the European long-term plans to develop 300GW of offshore wind in the North Sea by 2050 materializes. Sharing the risks will require completely new approaches, such as joint maritime spatial planning, interconnected offshore transmission grids, and hybrid offshore wind farms.

For example, offshore wind energy islands including hydrogen facilities at sea, might become a reliable power source if sufficient investments are made in the large-scale interconnections and development of supergrids for the deployment of offshore wind. For instance, in Greater China, the Indian Subcontinent and Europe, expansion of grids to cover larger market areas will move from interconnection to supergrids via extreme and ultra-high-voltage systems for long distance transmission.

High voltage direct current (HDVC) applications for interconnection and offshore wind integration projects are planned or already ongoing, driven by interconnection of non-synchronous networks, bulk power long-distance transmission within grids, and the connection of offshore wind farms.

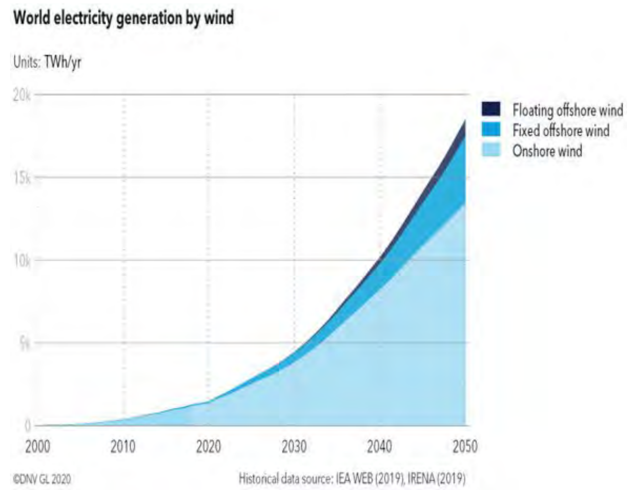
Governments in Europe are focusing increasingly on larger-scale and cross-border infrastructure projects. These projects will require additional market design and operating rules to support business models for offshore wind projects in cross-border hubs, as well as for the production and integration of green hydrogen in the energy system.

RENEWABLES COMMITMENT

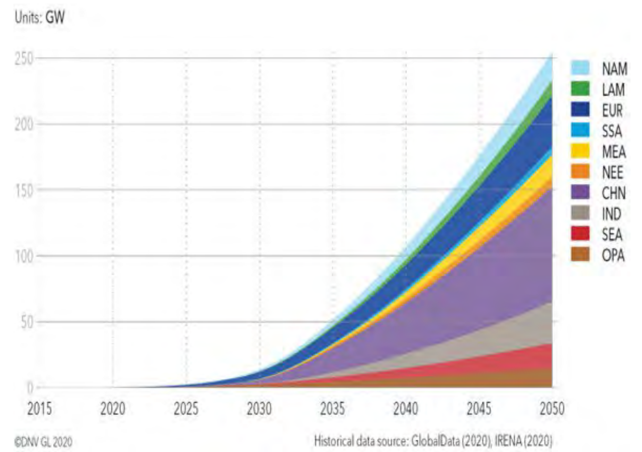
While it's encouraging to see increasing electricity generation from renewables, it is not without its challenges. New, unproven turbine technology deployed in extreme weather conditions, the lack of government frameworks in emerging markets, limited or aging transmission and grid capacity, all need to be addressed to make offshore wind a more appealing option for investors. The need for proper testing, adoption of international standards and independent certification will play a crucial role—as it has in the last 40 years—for prudent and proper project and technology risk mitigation.

Governments around the globe must commit to post-pandemic economic stimulus packages, bold policies and supportive infrastructure regulations that will drive the uptake of low or zero-carbon solutions, and such an approach will show to be good and sustainable use of public stimulus in a Post-COVID-19 economic situation. To truly accelerate the pace, higher carbon pricing, rapidly scaled and deployed renewable technology, expanded digitalized regional grid infrastructure, and greater energy-efficiency measures are urgently needed.

For more information, visit: *www.dnvgl.com*



» *Offshore wind will generate almost 9% of electricity globally by 2050, compared with 0.3% today. (Image credit: DNV GL)*



» *By 2050, floating offshore wind projects could have 255GW of installed capacity: more than a fifth of the offshore wind market. (Image credit: DNV GL)*

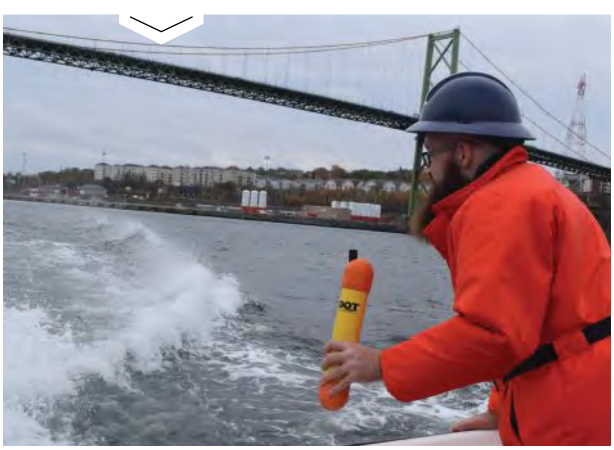
| **FEATURE** |

THE FUTURE OF **WET CHEMISTRY ON AUTONMOUS PLATFORMS**

By Vincent Sieben, *Director of Engineering, Dartmouth Ocean Technologies Inc.*

Taking a laboratory to sea onboard a robot sounds like science fiction. Yet small and automated analyzers are necessary, in part due to the payload constraints of ocean-going research platforms. Autonomous watercraft and long-range gliders are designed to keep energy consumption and physical size to a minimum. Is it even possible to perform subsurface automated titrations, colorimetric chemistry, chromatographic separations, or genetic analysis using a vehicle as small as BAE's Riptide™ micro AUV? What about the ever-expanding Biogeochemical ARGO initiative to include a suite of wet-chemical sensors? Or on dropsondes, such as Dartmouth Ocean Technologies' D-Profiler (*Figure 1*)? Possibly. But it would need to start with efficient fluid processing, a fluid processor if you will, onboard marine platforms to avoid bringing bathtubs or gallon-sized containers of reagent to sea for such analysis.

Modern and commercially available sensors designed to characterize primary production, detect harmful algae phytoplankton, measure nutrient and trace metal concentrations at nanomolar levels, or perform DNA amplification have limited deployment possibilities on marine platforms. Nitrate, phosphate, silicate, and ammonium sensors are often reagent-based and built by combining off-the-shelf pumps, valves, tubing, and interconnects. Such fluid routing makes sensors physically large, heavy on energy consumption, and excessively wasteful with reagent owing to inherent dead volumes. It is not uncommon for such systems to average milliliters of waste or reagent per sample measurement. Adding these sensors to fleets of small platforms/AUVs will not be technically feasible with such macro-scale sensor systems. Utilizing lab-on-chip microfluidic technologies can dramatically lower reagent consumption by performing the fluid routing on credit card-sized devices.



» *Figure 1: Dartmouth Ocean Technologies D-Profiler dropsonde platform. (Photo credit: Dartmouth Ocean Technologies Inc.)*

LAB-ON-CHIP BREAKTHROUGHS

Several research groups around the world are on this cutting-edge with notable efforts to miniaturize wet chemical analyzers. Teams include those at National Oceanography Center in Southampton (UK), Shandong University (China), Japan Agency for Marine-Earth Science and Technology (Japan), Monterey Bay Aquarium Research Institute (USA), and our group at Dalhousie University (Canada). The concept of micro-total-analysis systems, also known as lab-on-chip technology, was started in the early 1990s. The sensors are based on networks of micrometer-sized channels, approximately the diameter of a human hair, and naturally lend themselves toward lower reagent and energy consumption, as well as reduced physical size.

These microfabricated systems combine a wide range of technologies and often integrate optics, flow control, and electronics. However, most microfluidic systems are designed for standard pressure and temperature ranges, since the healthcare and pharmaceutical industries primarily require benchtop lab-grade systems. Very few lab-on-chip systems have been designed and created with the intention of *in-situ* deployment in the deep ocean. Engineering "submersible lab-on-chip sensors" has taken the community time, but there are a few start-up companies transitioning these devices out of research groups and into products for use around the globe.

Submersible lab-on-chip sensors are poised to transform *in-situ* sensing of marine environments. In the last 10 years of literature there have been numerous examples of spectrophotometric sensing on microfluidic platforms in marine environments for measuring nitrite, nitrate, orthophosphate, ammonium, silicate, chromium, iron, manganese, pH, and even crude oil components. These research projects will undoubtedly face numerous hurdles when they enter the product phase. I learned a great deal about how to make excellent products from lab-on-chip research projects, commercializing the first lab-on-chip sensor in the oil and gas industry, Schlumberger's MAZE™ microfluidic SARA.

OPTIMIZING FIELD APPLICATIONS

One of the key challenges that remains to be addressed in the marine space is serviceability of the nascent lab-on-chip sensor products. Many of the above-mentioned submersible lab-on-chip sensors use epoxy-set optics and bolt off-the-shelf solenoids to the lab-on-chip disc or device. Should field staff want to service the chip, they cannot and would have to send the entire canister package to the factory for refurbishment. To address these productization issues and advance lab-on-chip sensors to their fullest potential, Dalhousie Laboratory partnered with Arnold Furlong at Dartmouth Ocean Technologies Inc. in 2019.

The first hurdle to address was performing optical spectroscopy on a lab-on-chip device that could be removed from the main sensor canister, the stainless-steel portion of *Figure 3*. Sean Morgan and Edward Luy devised a brilliant technique called "inlaid optics™", which can be found published in the Journal of Micromechanics and Microengineering, 2020, vol. 30(9) by Luy et al. The microfabrication technique allows us to use low-cost LEDs and photodiodes to perform color measurements on extremely small volumes of fluid (4 μL)

over exceptionally long path lengths of 25 to 50 mm. Most importantly, this can be done without attaching optical elements to the chip itself. No more epoxy.

The next hurdle was to develop integrated valving to remove the bolted-on solenoids. The white ovals in *Figure 2* are our on-chip check valves that enable fluid routing on the lab-on-chip and completely avoid the need of affixing anything to our chip device. These two elements—the inlaid absorbance cells coupled with the on-chip check valves—have allowed us to design lab-on-chip sensors with field serviceability in mind. Being able to service the chip onboard a ship or in remote locations brings us one-step closer to widespread utilization of this exciting technology.

THE FUTURE

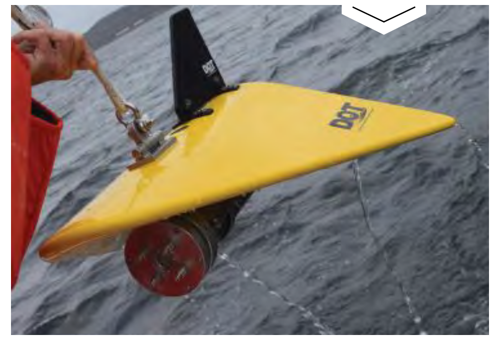
The future of wet chemistry on small autonomous platforms is bright. We have developed the smallest submersible lab-on-chip sensor for phosphate in the world. *Figure 2* shows the compact sensor, 3 inches in diameter and 12 inches long, yet still containing a wealth of fluid-processing capability with 8 on-chip valves and two absorbance spectroscopy cells of 5 mm and 25 mm length. The sensor does not compromise performance with a 50 nM – 100 µM phosphate detection range. Inside the sensor instrument housing of Figures 3 and 4, we have been able to add 3 separate syringe pumps and 4 optical sensing pairs (LEDs/photodiodes) to accommodate a wide variety of chemical protocols.

Making the lab-on-chip device removable enhanced serviceability and paved the way for Dartmouth Ocean Technologies Inc. to provide a variety of customizable chips. For instance, a lab-on-chip device that simultaneously measures two, three, or four species is possible without changing the sensor instrument canister. We can mail a small chip to a location, the user can swap the chip, and initiate a different wet-chemistry protocol. In the next 2-3 years, it is our aim to miniaturize an entire autoanalyzer on a device that can be slung underarm. In the next 5 years, expect to see multiple companies offering a multitude of such sensors on small autonomous platforms.

Tiny under-the-sea labs are the future.

For more information, visit:
www.dartmouthocean.com

» *Figure 2: An example lab-on-chip phosphate sensor. Patents pending. (Photo credit: Sieben Laboratory at Dalhousie University)*



» *Figure 4: Integration testing of the manufactured lab-on-chip phosphate sensor with a towed body V-wing. (Photo image: Dartmouth Ocean Technologies Inc.)*

» *Figure 3: Phosphate lab-on-chip sensor in a 2-canister configuration: one canister for reagent, standards and waste, and one canister for the sensor instrument that houses supporting electronics, pumps, and optics for running the lab-on-chip. (Photo credit: Dartmouth Ocean Technologies Inc.)*

| FEATURE |

THE FUTURE OF OF SUBSEA INSPECTIONS

By Chris Gibson, *VP Sales, Marketing & Business Development, VideoRay*

The rapid evolution of ocean technology is fast facilitating a new era of safer, more efficient and cost-effective subsea inspection. While Remotely Operated Vehicle (ROV) technology itself is nothing new, its evolution over the next decade will prove instrumental to the advances of the offshore activities. ROVs for underwater inspection and/or intervention—usually controlled from a topside asset—allow operators to react to real-time feedback and manage the ROV system accordingly and collect pertinent data and information. The best way to contextualize just how transformative ROV engineering will be over the next decade is to contrast it with today's technology. There are three areas of particular emphasis:

1. **Deployment and Recovery**—the associated costs and safety concerns

2. **Operating an ROV**—how it will become easier and more common

3. **The data**—how it is collected, presented, and how we use it

DEPLOYMENT AND RECOVERY

Deployment and recovery can be some of the most expensive phases of any ROV operation; they are also some of the most dangerous.

TODAY: Typically, ROVs are operated near the deployment point. As ROVs have become smaller and more capable, the deployment point has moved from a vessel to offshore platforms, resulting in significant cost savings. Additionally, as sensors have miniaturized, smaller ROVs are capable of doing much more than they could in the past and have helped significantly expand operational windows in harsh conditions.

THE NEXT DECADE: Advances in communications will increasingly allow for remote operation, removing operators from the dangers associated with traditional ROV deployment points. With a reliable internet connection, ROV pilots can work from a land-based command center instead of a pitching vessel or remote platform. Navy operators can deploy and control ROVs in a mine field from a safe distance. Over the coming years, eliminating the need for an operator to be physically near the ROV will solve many logistical problems, while saving time and money and improving safety.

OPERATING AN ROV

A common problem is the need for experienced operators to maneuver the ROV and its payload to obtain the necessary information. Piloting experience will be significantly improved over the next decade.

» *Greensea's Workspace software already includes features like automated waypoint following, search grid and station keeping among others making it much easier to complete missions. (Image credit: Greensea)*

» *The Defender deployed with dual Blueprint Lab multi-function manipulators. (Image credit: U.S. Naval Information Warfare Center)*

TODAY: The skill levels required to navigate an ROV, regardless of water depth or sea state, is often underestimated. Given that piloting is dependent on real-time operator response, it is also contingent on failproof communications and sensor feedback, all supported by high bandwidth and low latency. Today this challenge is addressed by applying control software based on sensor input to help place the ROV system in an automated flight control. Not dissimilar to the "autopilot" systems used in the aviation sector, software packages like Greensea's Workspace can hold an ROV's position without any piloting input at all. It can also locate and return to specific locations during period inspections. The bottom line with this kind of software is that the level of experience—and dexterity—required for operation is considerably less with this kind of software.

THE NEXT DECADE: Everyone wants the ROV tether to disappear, but it ensures real-time feedback. In short, it tells us what the ROV is seeing. Whilst high bandwidth wireless communications technology exists, it is important to note that the growing demand for subsea bandwidth outstrips what is feasible in marine environments. AUV technology, however, is already taking intelligent automation to the next level. In a very basic sense, an AUV is programmed to perform a mission before it is placed in the water; all the processing happens onboard the AUV, whereas ROV processing is performed topside at the operator's control. Today AUVs are programmed to inspect areas defined by coordinates. They navigate using a combination of sensors and positioning systems, sonar telemetry and even a camera image. As technology evolves these capabilities will be available on VideoRay's ROV systems.

THE DATA

Advances in sensor technology have transformed the way we work at sea and unlocked an ocean of data. How we collect, process and use this next wave of data will prove critical.

TODAY: More and more sensors are being deployed on ROVs to collect a wider range of information. Sensor fusion allows us to dynamically build georeferenced models from the data collected.

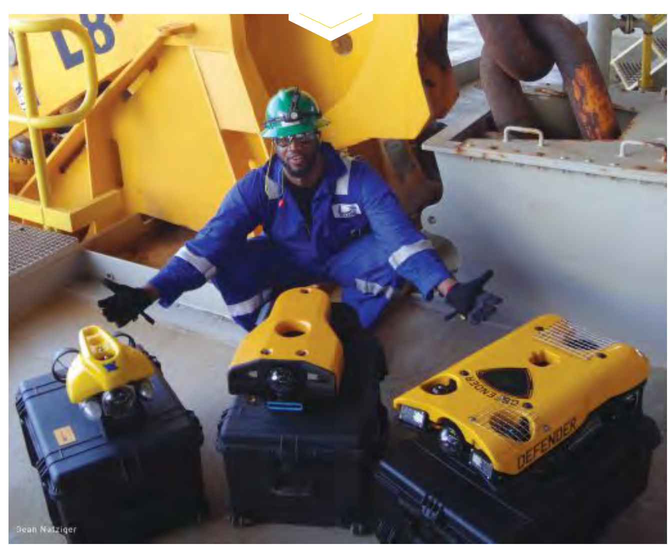
THE NEXT DECADE: The ability to deploy an ROV and produce a 3D point cloud model will become the norm, instead of just a video stream. As technology improves, these models will become more accurate and collect even more information. The models can then be used by the ROV to perform complex tasks with less and less need for a pilot or skilled operator, and can be done in low bandwidth, high latency systems.

This all sounds great in theory—but how does it work in practice?

All FPSO (Floating Production Storage and Offloading) vessels require periodic inspections to their hull, anchor chain, and subsurface infrastructure. The traditional inspection method—still in use by some firms today—is to hire an offshore service vessel with a work-class ROV to follow the anchor chain from the surface to the sea floor. Not only is this highly expensive but this operation poses significant risk to both assets; large work-class ROVs can damage the FPSO and moving mooring chains can damage the ROV.

TODAY: As a significant cost reduction, smaller ROVs are increasingly deployed and operated from the FPSO, sometimes using remote piloting expertise.

THE NEXT DECADE: Deep water inspections will be possible from Automated Surface Vessels (ASVs) and either controlled from the FPSO (via RF or WIFI links) or from a remote location using a satellite or even a Starlink connection. The problem with a satellite link is latency. The telemetry stream lag makes the ROV system near impossible to operate. With the help of AI and AUV technology, VideoRay ROVs will be able to perform semi-autonomous inspections, voiding the latency issue introduced by these types of connections. Measurements will not use tools but will be calculated from the 3D models and compared to previous inspections. Applications for distance deployment and recovery, semi-automated control and better 3D point cloud models flow across all underwater applications, including defense, renewables, port inspection, security, customs and border guard operations, and aquaculture markets.



» *VideoRay's three ROV models, from left to right, are the Pro 4, the Pro 5, and the Defender. Photo credit: Dean Nafziger. (Photo credit: VideoRay)*

| FEATURE |

THE FUTURE OF **FLOATING OFFSHORE WIND**

By Sam Leighton,
Managing Director, Bombora

» Bombora's innovative Integrated solution combines wind and wave power generation on one single floating platform, with the potential to deliver 18MW and a significantly lower LCOE. (Image credit: Bombora)

The future of floating offshore wind could be a question of how to integrate wave energy as a means of achieving a reduction in the Levelized Cost of Energy (LCOE).

Eighty percent of the world's offshore wind resource is located in deep water areas and currently only accessible through floating offshore wind projects. These pioneering initiatives are paving the way for us to capitalize on this vast opportunity and, by the end of this decade, are expected to make offshore wind an increasingly competitive form of large-scale and sustainable renewable energy. With BloombergNEF forecasting over 3.5GW commissioned by 2030, this expanding floating offshore wind market will inevitably open-up considerable supply chain opportunities and challenges for industry.

According to IRENA, the LCOE for fixed bottom wind decreased by 29% from 2010 – 2019, a period which saw a ninefold increase in the installed capacity. The lure of unlocking greater potential by accessing deep water sites, combined with the promise of higher average capacity factor will drive deployment of more and more floating wind projects. The resulting impact of this high-volume scale-up will drive down the LCOE, mirroring the trend experienced by bottom fixed wind a decade ago.

» Bombora's patented mWave™ is a unique modular system of flexible rubber membrane covered cell units, each 15 meters in length. (Photo credit: Bombora)

The question on the minds of offshore energy developers is "how can we accelerate the pathway to a competitive LCOE?" Imagine a scenario whereby it was possible to immediately reduce the LCOE by 10-20%. The team at Bombora, the company behind the unique membrane-style wave energy converter system, is developing an integrated floating wind platform that incorporates its patented mWave™ product. This new hybrid system can deliver this level of reduction in LCOE.

Bombora has made significant progress on the performance design and modelling, as well as cost of energy analysis to partner wind with our mWave technology to optimize offshore power projects.

PAIRING WAVE AND WIND ENERGY

Pairing ocean wave energy with offshore wind has the potential to be a technology game changer, with Bombora's mWave either co-located or integrated in the foundation of a floating offshore wind platform. The pairing presents four major benefits to offshore wind developers:

1. Reduced cost of energy through shared infrastructure costs

    Integrating or co-locating offshore mWave technology with floating wind turbines will result in shared cost of both civil and electrical infrastructure, including export cable and grid. For an integrated solution, the cost reduction benefits are further increased with a shared floating structure. The incremental costs of scaling up both the civil Balance of Plant (BoP), specifically platform size and mooring strength, as well as electrical BoP, specifically export cable and grid connection

infrastructure, are significantly lower than two stand-alone projects, each providing its own BoP infrastructure. The existing synergy between the Civil and Electrical Balance of Plant for Floating Wind and Floating Wave systems is significant.

2. Seabed lease area optimization

Integrating or co-locating offshore mWave technology with floating wind turbines has the potential to increase the installed capacity of a seabed lease area by 50% without increasing its footprint.

3. Consistency of power supply

Waves are more persistent and predictable than wind. Combining wave and wind power production can deliver greater consistency and predictability of a project's energy production. mWave generates power more consistently across the full range of wind speeds thanks to the low correlation between the wind and wave resource.

4. Improved onsite operations and maintenance with standardized vessels

The synergies for Floating Wind and Floating Wave do not stop at the capital equipment. The floating systems can be installed and maintained using standard offshore service vessels. Floating systems can be built and commissioned onshore, before simply being towed to site and connected. Operations and maintenance advantages extend even further with floating wave systems, as all critical maintenance can be performed onsite with standard offshore construction vessels.

PARTNERING TO ACCELERATE DEVELOPMENT

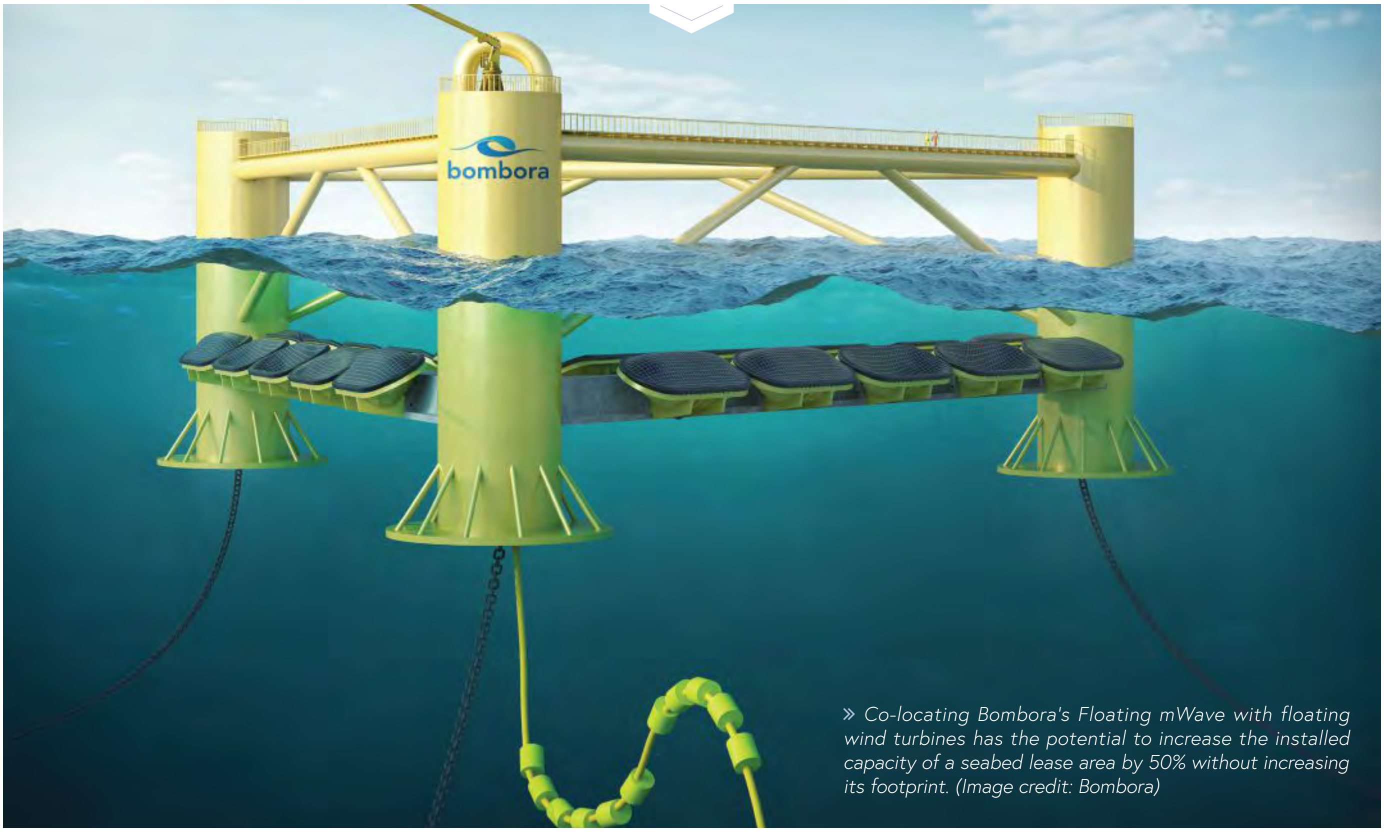
In October this year, Bombora partnered with TechnipFMC, a global marine EPCI contractor. The partnership is focusing on a solution with the potential to deliver up to 18MW of combined wave and wind power from a single platform at a targeted LCOE of €50/MWh or less by the end of this decade.

The partnership has named the joint project InSPIRE, and is initially targeting a 12MW demonstration project comprising 4MW mWave and 8MW Wind. It is the intent for the InSPIRE project to prove the benefits of marrying the two technologies and to validate the €50/MWh LCOE target.

The InSPIRE project builds on an earlier collaborative study with offshore engineering specialists Apollo. Bombora continues to progress its evaluation project with the Offshore Renewable Energy Catapult's Marine Energy Engineering Centre of Excellence (MEECE). This project is utilizing the full techno-commercial capabilities of MEECE to optimize the performance and cost of Bombora's mWave™ technology in an offshore environment.

Bombora believes that ocean energy technology can deliver large-scale renewable power and contribute to a more sustainable global energy supply in accord with the 2050 Paris Agreement climate targets. Utilizing all the available natural resource offered by wind and wave in a seabed lease area appears to be the obvious and logical next step to reduce LCOE. The integrated mWave platform heralds a breakthrough for the future of ocean energy technology.

For more information, visit: www.bomborawave.com



» *Co-locating Bombora's Floating mWave with floating wind turbines has the potential to increase the installed capacity of a seabed lease area by 50% without increasing its footprint. (Image credit: Bombora)*

| FEATURE |

THE FUTURE OF AUV DEVELOPMENT

By Tobias Stapleton, *Co-Founder, Blue Innovation Symposium*

The future of autonomous underwater vehicle (AUV) development is central to the work at Dive Technologies, a Massachusetts based company developing their large displacement AUV, DIVE-LD. Jim Bellingham, Director of the Center for Marine Robotics (CMR) at the Woods Hole Oceanographic Institute (WHOI), recently noted that, "Dive Technologies is expanding the market for large vehicles to the deep ocean, which will undoubtedly create new opportunities both in the application domain and for payload developers."

The company was formed in 2018 and in less than two years has made rapid progress, having already completed sea trials of the DIVE-LD. To bring a vehicle of this size, endurance, and depth rating to market so quickly required the team to reimagine their manufacturing processes, hire new team members, and form strategic partnerships.

The team quickly realized that they would need to prioritize cutting-edge design and utilize new techniques such as 3D printing for the outer shell of the DIVE-LD, which required a very sophisticated large format additive manufacturing (LFAM) process. The process that Dive used was created through a Cooperative Research and Development Agreement (CRADA) with the Oak Ridge National Laboratory (ORNL). However, 3D printing a surface area that large, posed challenges. The end product had a rough, corduroy-like appearance. To mitigate this, the team spent several months developing a coating process to smooth the outside of the vehicle, which also served to strengthen the hull and reduce post-manufacturing costs.

» DIVE-LD, a large displacement AUV

Once the hull was certified to resist the desired 6,000 meters of pressure, it was on to the test tanks at WHOI, where the team realized that not only had they developed a novel way to build a prototype, but a new way to manufacture a vehicle.

KEY DEVELOPMENT DECISIONS

In the early days of Dive, the team made several "make or buy" decisions on key systems, opting to buy top-of-the-line thruster, battery, and navigation systems, while focusing their expertise on building certain customized systems in-house. The team found that by incorporating key Commercial Off the Shelf (COTS) components with these customized systems—designed by in-house subsea engineers—they were able to rapidly integrate and test the DIVE-LD.

Hiring was also key, as co-founder and CTO Bill Lebo explains: "We picked a unique group of experienced subsea engineers that share a rapid prototyping, rapid build, fix, test, and repeat mindset. We were able to form a team with deep industry experience." Located in the Boston area, Dive is well positioned to attract talent experienced talent from Maine to Rhode Island.

Partnership development was the third key to Dive's success. "As a small company, you have to value partnerships. We were fortunate enough to form early partnerships with a number of key organizations," explains Bill Lebo. While considering critical make/buy decisions, the team also had to assess the need to develop a brand-new vehicle controlling software. That is when they were introduced to two Virginia Tech researchers, Professor Dr. Dan Stillwell, Autonomy and Robotics lab at VT, and Associate Professor Dr. Stefano Brizzolara, Center for

Marine Autonomy and Robotics at VT. Dr. Stillwell's team had been developing AUV flight control software, operating systems, and had moved to the Robot Operation System (ROS), which the Dive team already knew they wanted to incorporate. Dive entered into a partnership with Virginia Tech through a Sponsored Research Agreement (SRA) and have, since, hired their own small software team to integrate and refine the code base developed at Virginia Tech. The connection with Dr. Stillwell and Dr. Brizzolara has helped Dive further develop important public and private sector relationships.

COMMERCIAL PARTNERSHIPS

The team approached commercial partnerships in much the same way. Early on, Dive approached Canadian outfit Kraken Robotics, because their pressure tolerant SeaPower AUV batteries had a reputation for being highly reliable. When Dive developed a matrix that outlined the key parameters needed in a battery, Kraken Robotics' 6,000-meter rated lithium-polymer batteries were deemed "head and shoulders" above the rest. Bill Lebo explains: "We have a lot of batteries in our vehicle, so it was important to get this right. We hopped on a plane, flew to Canada (pre-COVID), and sat down with the Kraken team to discuss our goals. We not only learned a lot about batteries, but also sonar systems which resulted in Dive integrating the Kraken sonar system into our vehicle." This partnership also led to Dive building a vehicle that will be operated by Kraken Robotics and is set to be delivered in Spring 2021.

Another key partnership was with Sonardyne. Starting out, Dive engineers weren't sure how certain systems, like the navigation system and the acoustical modem, were going to work through their unique hull, which had distinct acoustical properties. Sonardyne took on the testing in their UK-based lab to better understand how their acoustic sensors would work in the Dive vehicle, resulting in key data before even going to sea trials.

NEXT GENERATION AUTONOMY

Given the DIVE-LD and the amount of batteries required to complete a 10-day mission, Dive believed that they would need a degree of situational awareness of the vehicle that a typical vehicle controller might not afford. The team knew they needed an advanced autonomy layer. And so, they reached out to Metron, based in Reston, VA, an outfit that helped Dive develop this advanced autonomy layer which sits on a completely separate computer on the Dive vehicle. Bill Lebo, explains, "We call it the backseat driver; it monitors operations and can make decisions autonomously, independent of an operator. The system can predict faults early and, if necessary, abort/end a mission to ensure the vehicle doesn't fail offshore."

While Dive has charted significant accomplishments over the last two years, COVID-19 has impacted their business development activities in 2020. Bill Lebo explains: "We have to be responsive and tenacious, particularly since a small group of engineers also needs to act as our supply chain and sales team." Geography, and tenacity, have helped the company in this regard; being located in the Northeast means close proximity to key organizations, such as the Navy, the Naval Undersea Warfare Center, WHOI, and are even within a short drive to Washington DC.

The rapid development and commercialization of innovative AUVs will be key to addressing the significant challenges—and opportunities—faced by the defense, research, and energy sectors. Dive Technologies, with their experienced team, innovative manufacturing processes, and their unique approach to developing partnerships, is leading the way with their DIVE-LD. To learn more, visit *www.divetechnologies.com*

» *DIVE-LD is depth-rated to 6,000 m*

» *DIVE-LD's autonomy system can predict faults early and, if necessary, abort/end a mission to ensure the vehicle doesn't fail offshore*

FEATURE

THE FUTURE OF VARIABLE AUTONOMY FOR UNCREWED SYSTEMS

By Scott Reed,
Chief Technology Officer, SeeByte

Uncrewed systems are used across all domains for applications including security, inspection, repair and maintenance of critical infrastructure, and scientific exploration. These are aimed at reducing the risk to human life and decreasing costs of operations, but this vision has yet to materialize due to the current levels of infrastructure and personnel required to support missions.

The maritime environment is becoming more complex, with command teams needing to assimilate increasing volumes of data and information from uncrewed systems. Planning and controlling the mission requires the ability to monitor multiple parameters, prioritizing and using information from many sources to make decisions.

Early vehicles executed pre-programmed missions defined waypoints. Missions were planned using proprietary software specific to a vehicle, with no autonomy onboard. Overtime, the C2 software evolved, building on emerging Common Data Model concepts, allowing a single software suite to plan missions for vehicles from multiple vendors. This reduced support logistics and operator training burden, and being vehicle agnostic, the end customers could confidently procure "best of breed" assets leveraging a "plug and play" approach.

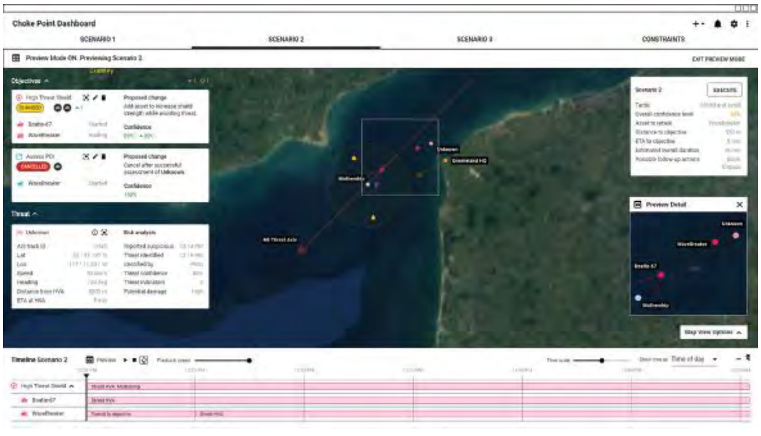
MACHINE LEARING & A.I.

Commercial autonomy architectures have since developed, which run onboard the vehicles, allowing machine learning and A.I algorithms to adapt to the environment, optimizing the mission. The operator can focus on what the mission will do (Goal-Based Mission Planning) while the onboard A.I determines how the tasks will be done. Collaborative multi-vehicle missions have been demonstrated, where the autonomy installed on multiple vehicles work together to intelligently execute tasks.

The availability of reliable high bandwidth communications in the above-water environment permits a greater connectivity between the uncrewed systems and command teams. The operator can remotely pilot a vehicle, stream live sensor data and supervise multiple vehicles simultaneously. They have access to increased volumes of information from multiple sources which can impact timely decision making and induce fatigue and information overload.

A multi-domain C2 system must be able to plan, monitor and re-plan missions for a large number of assets. This has led to the formalization of common data models to describe the principle components of the mission. Defined software interface standards also allow a single common C2 system to plan and control many different vehicle types.

The availability of reliable communications above water between the C2 system and assets allow an operator to carry out complex missions without the requirement for advanced Autonomy or A.I. agents. In comparison, the lack of communications underwater has created the need for advanced Autonomy and A.I onboard the uncrewed vehicles in this domain. This capability has been successfully applied in constrained problem spaces such as Mine Counter Measures (MCM) operations but have yet to be used reliably in more complex scenarios.



» *Variable Autonomy will allow A.I. to assist operators in complex mission planning and execution, even when communications degrade. (Image credit: SeeByte)*

» UUV uses A.I to adapt the mission to inspect a possible manmade target detected by a machine learning algorithm. (Image credit: SeeByte)

VARIABLE AUTONOMY

Variable Autonomy, where decision making authority can flow seamlessly between the operator and the A.I, will reduce the reliance on high bandwidth persistent communications for complex missions, employing increased levels of A.I. both onboard the assets and within the C2 chain.

Emerging applications, such as offshore inspection, repair, maintenance and asset protection, involve more complexity and variability, and require a step change in the adaptability of the onboard Machine Learning and A.I algorithms, and a more fluid interaction with the operator(s) for complex decision making. The variable autonomy concept will be essential for these future operations.

The idea blends concepts from both the above and sub-surface spaces. A.I. will operate across the different layers of the network, functioning both as a smart decision aid when the operator is in control, but capable of transitioning to onboard decision making when communications falter. Rapid recommendations will be provided to the operator when the re-planning of multiple assets is required; it will also allow the uncrewed systems to revert to a more traditional "autonomy" paradigm when communications fail, with decisions made onboard the assets.

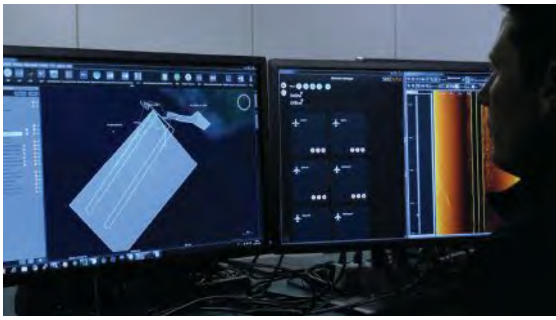
The variable nature of the environment and threat context creates requirements around prediction so collaboration can continue when communications degrade. Current systems often initiate simple safety behaviors to abort the mission when communications drop, which reduces mission effectiveness but maintains operator trust. Prediction capabilities will allow the operator to maintain trust and situational awareness of the mission as communications fluctuate.

The operator and crewed and uncrewed assets must all maintain a "world model" view of the mission, building a common understanding of the environment. The system must be tolerant to these world models diverging as communications drop. Variable autonomy success also requires the ability to prioritize interactions and data exchanges based on the rules of engagement and communication limitations, and to transfer that data and instructions in an intelligent manner.

ENHANCING OPERATOR EXPERIENCE

The User Experience (UX) must allow the operator to quickly visualize updates and predictions from many systems, along with recommendations from the A.I Agents(s). Operators must be able to fluidly interact with the assets to adapt mission plans as necessary. A.I. recommendations must be explainable and provide rapid rehearsals of recommended solutions to ensure operator trust.

Variable Autonomy will enable a step change in the complexity of missions that can be currently executed by fully autonomous systems. It will couple the complex decision-making ability of the human operator, with the advanced Autonomy and A.I Agent's ability to monitor vast volumes of data and rapidly propose, rehearse and present solutions to the changing environment and tactical situation. Machine learning algorithms will provide contextual information for decision making; A.I., operating across the different levels of the network, will propose task assignments for large numbers of assets based on operator input; the onboard Autonomy will provide a safety net, allowing the mission to continue to execute the command intent if communications are degraded.



» SeeByte's Data Core and SeeTrack tools maintain a "world model" of the mission to support the operators. (Image credit: L3 Harris)

Effective teaming requires that delegated authority can transition between the operator and A.I Agents in a trusted and consistent way. It creates the concept of an autonomy spectrum within which the operator and systems operate, with the classical C2 paradigm at one end and full A.I. enabled autonomy at the other. Allowing the threshold on where decisions are made to vary and blurring the classic boundaries between human driven C2 and full A.I Agency will produce a more flexible solution suitable for the emerging problems that uncrewed systems are being considered for.

For more information, visit: www.seebyte.com

» Deep-sea RROVs need high strength syntactic foam materials capable of withstanding extreme conditions and constant hydrostatic pressure. (Image credit: Trelleborg)

| FEATURE |

THE FUTURE OF **SYNTACTIC FOAM FOR RESIDENT ROV APPLICATIONS**

By Dr. Muhammad I. Ali*, Zaki Akhtar, *Trelleborg Applied Technologies*

There is a paradigm shift towards the use of Resident ROV (RROV) systems, mainly driven by the cost savings and operational benefits for oil and gas, and offshore wind energy industries. This has fueled global research projects in two main areas of RROV technology development:

- Development of integrated communication and navigations systems (software, hardware, sensors and battery packs)
- Development of syntactic foam buoyancy materials

RROVs deployed at deep-sea and ultra-deep-sea depths demand maximum durability. The lack of higher strength syntactic foam materials, capable of withstanding the extreme conditions and constant hydrostatic pressure experienced at depth for extended periods, is one of the major barriers to the commercialization of RROV technology.

Published research shows that existing RROV submersibles only provide a maximum service lifetime of up to six months when permanently deployed in deep-sea (2,500-4,000 MSW) and ultra-deep-sea (5,000-6,000 MSW) applications.

This brings a new challenge to materials scientists and engineers, to develop innovative syntactic materials that offer serviceability well beyond six months, to a much longer duration of around two years to support the needs of the industry.

Recognizing these new requirements for long term submersion, Trelleborg's applied technologies operation undertook a program of development, testing and qualification of syntactic foam materials to address the specific and more demanding needs in RROV applications, aiming to ensure robust and reliable performance.

DEVELOPMENT OF SYNTACTIC FOAM

A systematic approach was adopted by Trelleborg in identifying potentially suitable syntactic foam materials. Derived from a combination of unique thermoset polymer matrices and high strength hollow glass microsphere (HGMS) technology, TG-1000R, TG-2000R, TG-3000R, TG-6000R with depth ratings of 1000, 2000, 3000 and 6000 MSW respectively, all underwent a stringent testing and qualification processes.

The evaluation of several resin matrix systems along with the screening of various grades of commercially available HGMS, and in-situ and ex-situ surface functionalization HGMS, were also included in the process.

Key performance indicators (KPIs) investigated during screening included:

1. Density
2. Hydrostatic Crush Pressure (HCP)
3. Water Absorption

TESTING PARAMETERS

Data had to be collected at specific timed intervals for analysis. This led to the development of an accelerated ageing test methodology, which allowed faster acquisition of data to accurately predict the material service lifetime, simulating the real-life application and reducing test program duration.

Water absorption was identified as one of the most critical parameters in the performance of syntactic foam materials for long-term immersion in deep-sea and ultra-deep-sea applications. Therefore, this became the focus of most of the testing and qualification.

The water absorption data was tested for fit to Fickian and Arrhenius models. The Arrhenius model was used to make

service lifetime predictions. This was followed by the validation of the model under real life conditions, at temperatures of +10°C or lower to replicate the temperatures experienced by RROV at depth ratings below 500 MSW.

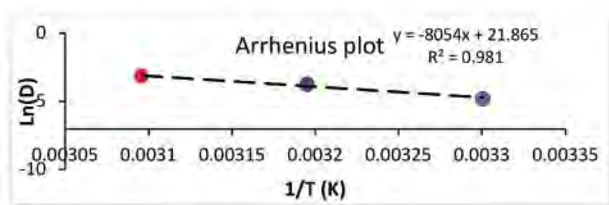
TESTING PROGRAM

Comprehensive testing was performed on numerous development samples using Trelleborg's in-house pressure testing facilities. Water uptake findings and results for Trelleborg's TG-3000R material, which was subjected to ageing at different temperatures in the range of +10°C to +50°C under the operational pressure of 310 bar are highlighted in table 1.

Table 1. Details of the samples used in this study

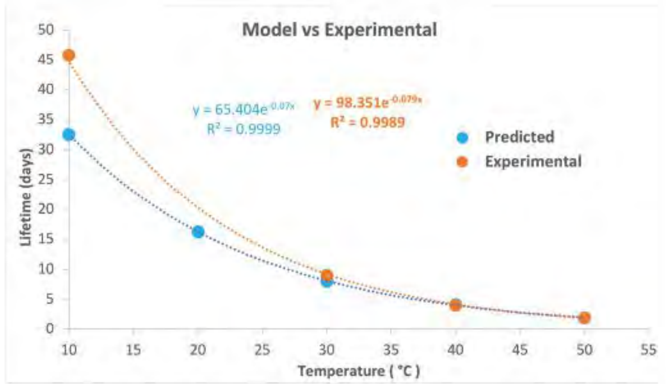
NO	Cube/cylinder	Dimensions	S/V
1	Cube	100mm x100mm x 100mm	0.06
2	Cube	50mm x 50mm x 50mm	0.12
3	Cube	30mm x 30mm x 30mm	0.20
4	Cube	20mm x 20mm x 20mm	0.30
5	cylinder	25.4mm (diameter) x 50.8mm (length)	0.20

A pass/fail criterion was set at less than 2% water absorption, which is Trelleborg's internal standard for buoyancy material testing for short-term cyclic applications. Initial experiments were performed at elevated temperatures, with data used to verify whether the Arrhenius Law was followed. By plotting the water absorption against the inverse of absolute temperature, a straight-line relationship with good correlation coefficients validate the Arrhenius fit as shown in figure 1.



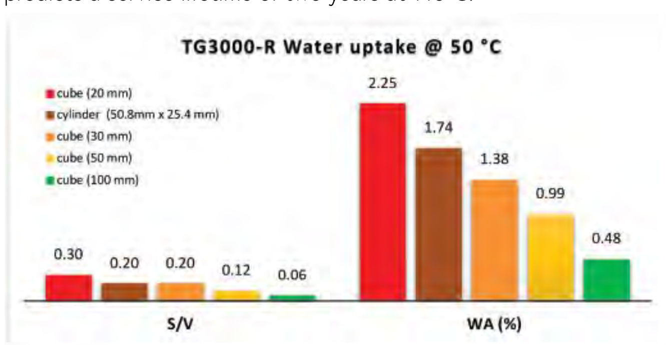
» *Figure 1. Arrhenius plot of TG3000-R at temperatures of +30°C, +40°C & +50°C respectively. The graph shows a linear fit with good correlation coefficient. This clearly shows that material follows Arrhenius law in accelerated ageing and data can be extrapolated to predict the service lifetime at lower temperatures.*

Stage two of testing, included experiments carried out at +10°C in order to validate the model. The graph in figure 2 shows the results of model and experimental data for comparison. The service lifetime predicted by the model based on water absorption values from accelerated ageing data, aligns with experimental data at +10°C. The graph in figure 2 also shows that the model is slightly more conservative in prediction of service lifetime than observed in validation experiments in a model of 32 days versus an experiment of 45 days. Since diffusion process is better followed at lower temperatures and as the temperature increases a deviation from pure diffusion behavior is observed as other factors (hydrolysis of glass microspheres and degradation of polymer matrix) contributing to the water ingress become important. This trend has been found in repeated experiments, giving confidence in the reliability and accuracy of the model.



» *Figure 2. Graph showing validation of model for water uptake. The predicted lifetime by model shows close agreement with experimental data.*

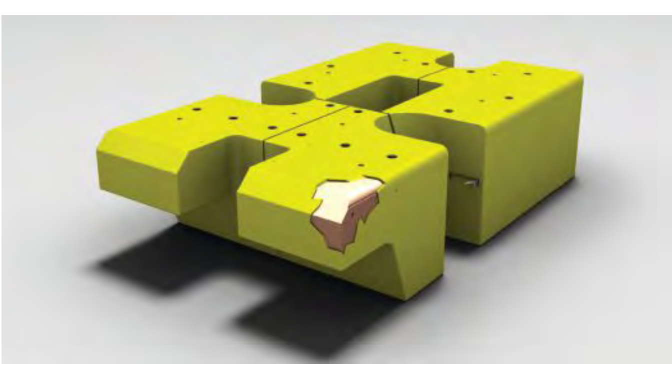
After the successful validation of the model, Trelleborg launched an extensive testing program on its TG-R range of materials utilizing both cube and cylinder specimens (different S/V ratio). For this purpose, TG-3000R syntactic foam material was chosen for testing, undergoing accelerated ageing at +50°C under hydrostatic pressure of 310 bar, the pressure at operational depth of 3100 MSW, until the material reached 2% water absorption; the failure index value (shown in figure 3). Validation experiments were set to run in parallel with the accelerated ageing, with data used to predict the service lifetime. The output of the model using the water absorption data at +50°C predicts a service lifetime of two years at +10°C.



» *Figure 3. TG3000-R after 42 days of immersion at +50°C. The data shows the water uptake is dependent on S/V ratio and sample geometry. The graph also shows relationships between S/V and water uptake, higher the S/V and higher the water uptake. Modelling of this data predicts service lifetime of two years at +10°C.*

SUMMARY

Trelleborg's applied technologies operation recognized the need for superior buoyancy to meet the more demanding requirements of RROVs. It developed and validated simple predictive models resulting in the identification of three syntactic materials capable of resident operation. Trelleborg's TG-1000R, TG-2000R and TG-3000R materials are unique within the materials buoyancy sector being fully qualified for long-term continuous use at maximum operational pressure for up to two years. Validation and testing will commence shortly on TG-6000R material to confirm reliability for RROV applications at increased depths. *www.trelleborg.com/applied-technologies*



» *Trelleborg's TG-R Buoyancy Module. (Image credit: Trelleborg)*

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E-mail: sales@deepwb.com
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4033 Ruffin Rd.
San Diego, CA 92123
Phone: 858 576 261
Fax: 858 576 0219
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Fax: +1 805 487 0427
USA: +1 888 BIRNS 88 (+1 888 247 6788)
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Fax: +1 401 753 6342
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Website: www.birnsaquamate.com
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Website: www.km.kongsberg.com/seatex
Contact: Finn Otto Sanne at finn.otto.sanne@kongsberg.com

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Website: www.km.kongsberg.com/seatex
Contact: Finn Otto Sanne at finn.otto.sanne@kongsberg.com

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Contact person: Tim Laws at sales@advancednavigation.com

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N-7462 Trondheim, Norway
Phone: +47 73 54 55 00
Fax: +47 73 51 50 20
E-mail: km.seatex.sales@kongsberg.com
Website: www.km.kongsberg.com/seatex
Contact: Finn Otto Sanne at finn.otto.sanne@kongsberg.com

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15375 Barranca Parkway, Ste I-112
Irvine, CA 92617
Phone: +1 949 727 9399
E-mail: sales@rjeint.com
Website: www.rjeint.com
Contact: Bruce O'Bannon

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Phone: +47 73 54 55 00
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Website: www.km.kongsberg.com/seatex
Contact: Finn Otto Sanne at finn.otto.sanne@kongsberg.com

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13431 NE 20th St.
Bellevue, WA 98005
Phone: +1 425 643 9866
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Skeidaras 12, 210
Gardabaer, Iceland
Phone: +354 533 6060
Fax: +354 533 6069
E-mail: baldur@star-oddi.com
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CORTLAND COMPANY
10633 West Airport Blvd Ste 300
Stafford TX 77477
Phone: +1 832 833 8000
E-mail: cortland@cortlandcompany.com
Website: www.cortlandcompany.com
Contact: Slobodan Nikolic

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4 Little Brook Rd.
West Wareham, MA 02576
Phone: +1-508 291 0057
E-mail: info@edgetech.com
Website: www.edgetech.com
Contact: Amy LaRose

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209 – 1875 Broadway Street
Port Coquitlam, BC
V3C 4Z1 Canada
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Contact: Steve Curnew

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11 Klein Drive
Salem, NH 03079
Phone: +1 603 893 6131
International: 603 893 6131
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Website: www.kleinmarinesystems.com

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Nygardsviken 1, 5165
Laksevag, Norway
Phone: +47 56 11 30 66,
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Website: www.saivas.no
Contact: Gunnar Sagstad

- STD/CTD, Sound Velocity probes/recorder with optional multi-parameter facilities; Turbidity, Fluorescence, Oxygen etc. The new CTD/STD model SD208 with wireless communication and high accuracy: 0.002 mS/cm, 0.002 °C.
- Precision pressure /depth (0.01% accuracy) and temperature sensors/recorders. Applications: hydrographic profilings, installation on ROVs and towed systems, etc. Robust and compact designs are combined with accuracy and "plug and play" compatibility. Output format for sonar equipment, e.g. EM1002, EM3000, SSP, HiPAP and Reson 8125.

SUBSEA FABRICATION

NEW INDUSTRIES
6032 Railroad Avenue
Morgan City, LA 70380
Phone: +1 985 385 6789
E-mail: bill.new@newindustries.com
Website: www.newindustries.com
Contact: Bill New

New Industries provides quality fabrication services to the offshore oil & gas and marine industries focusing on large diameter pressure vessels, suction piles, DNV buildings and deepwater subsea production equipment such as jumpers, PLETs, PLEMs and manifolds.

SUBSEA TECHNOLOGY

SUBCTECH GMBH
Wellseedamm 1-3, 24145 Kiel,
Germany
Phone: +49 431 22039 880
Fax: +49 431 22039 881
E-mail: info@subctech.com
Website: www.subctech.com

Ocean Power: Leading manufacturer of Subsea Oil+Gas, Storage, UPS, ROV and AUV vehicle Li-Ion batteries - fully approved according API17F, MIL-STD, UN T38.3 etc. to guarantee highest efficiency, reliability and safety for your jobs.

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553 South Street
Quincy, MA 02169
Phone: +1 617 715 7000
E-mail: adam.mara@gd-ms.com
Website: gdmissionsystems.com/underwater-vehicles/bluefin-robotics
Contact: Adam Mara

General Dynamics Mission Systems' Bluefin Robotics products provide undersea capabilities for defense, scientific and maritime customers worldwide. Bluefin Robotics products offer a range of systems and configurations that can operate in the open ocean and in constrained waterways. Our core autonomous product line includes Bluefin SandShark, Bluefin-9, Bluefin-12, and Bluefin-21, Hovering Autonomous Underwater Vehicle (HAUV), and Subsea Power technologies.

The Bluefin Robotics AUV family shares a free-flooded, modular, and open architecture backbone that has enabled the integration of 70+ sensors. We have developed and delivered AUVS worldwide to research institutes and industry and have provided AUVS to the United States' and International Navies.

INTERNATIONAL SUBMARINE ENGINEERING LTD. (ISE)

1734 Broadway Street,
Port Coquitlam, BC, V3C 2M8
Phone: +1 604 942 5223
E-mail: info@ise.bc.ca
Website: https://ise.bc.ca/

International Submarine Engineering Ltd. (ISE) is a world leader in the design and integration of autonomous and remotely operated robotic vehicles and terrestrial robotics. Over our 40+ years in business, we have accumulated a great deal of expertise in the design, manufacture, and maintenance of:

- Autonomous Underwater Vehicles (AUVs)
- Remotely Operated Vehicles (ROVs) for subsea operation
- Human Occupied (HO) submersibles
- Customized systems for the offshore oil industry
- Customized systems for the Military-Naval sector
- Hydraulic, pneumatic, and electric robotic manipulators
- Teleoperated and autonomous robotic systems
- Robotic systems for nuclear Industry applications
- Communications and real-time control system

L3 HARRIS (OCEANSERVER)

275 Martine Street
Fall River, MA 02723 USA
Phone: +1 508 678 0550
Fax: +1 508 678 0552
E-mail: IVER.Sales@L3Harris.com
Website: www.L3Harris.com
Contact: Jim Kirk

L3Harris Technologies is an agile global aerospace and defense technology innovator, delivering end-to-end solutions that meet customers' mission-critical needs. The company provides advanced defense and commercial technologies across air, land, sea, space and cyber domains.

L3Harris OceanServer develops autonomous, lightweight Unmanned Undersea Vehicles. L3Harris OceanServer has established itself as the leader in man portable UUVs, providing highly capable vehicles to a wide array of military, commercial and research customers. With over 15 years experience in the underwater field, our engineers have developed a reliable and easy to use platform that is trusted to complete marine missions all around the world.

MARISCOPE MEERESTECHNIK

Eichkoppel 21, 24214 Gettorf,
Germany
Phone: +49 4346 6000 490
E-mail: info@mariscope.de
Website: www.mariscope.de
Contact: Niklas Becker

With more than 25 years of experience in the design, development and manufacture of ROV's and towed systems, Mariscope is one of the very few companies that can offer you really customized underwater solutions with actual integration. Instead of just adding accessories or instruments to our vehicles, we design, develop and manufacture the completely integrated solution to the client´s needs.

Mariscope offers from small towed systems or compact Observation Class ROVs up to complete multifunction units. The company also provides other solutions such as antifouling devices, side-scan sonars, oceanographic instruments for ports and offshore platforms (current/wave meters), or even manned submarines.

OUTLAND TECHNOLOGY

38190 Commercial Ct.
Slidell, LA 70458 USA
Phone: 985 847 1104
Fax: 985 847 1106
E-mail: jeff@outlandtech.com
Website: www.outlandtech.com
Contact: Jeff Mayfield

Offering the most rugged equipment and unsurpassed customer service, Outland Technology has been the world's leading manufacturer of underwater video, lighting and ROV equipment for over 30 years. We recognize that no two jobs are the same and specialize in products that are customizable for your specific applications.

SEAMOR MARINE LTD.

1914 Northfield Road,
Nanaimo BC V9S 3B5 Canada
Phone: +1 250 729 8899
E-mail: sales@seamor.com
Website: www.seamor.com
Contact: Simon Douthwaite

We design, research and manufacture SEAMOR ROVs and related accessories. The SEAMOR ROVs are at the forefront of the expansion of marine industries and research, providing safe and cost-effective eyes underwater to help guide industrial activity and monitor the health of underwater ecosystems. Our ROVs are very unique because of their modular design and their wide range of capabilities. Our engineers have developed system components (vehicle, controller, tether and power source) to be interchangeable across our product line; Mako, Chinook, and Steelhead. SEAMOR vehicles are quality machines and are built to last. Our vehicles can be easily upgraded and repaired.

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OKEANUS SCIENCE & TECHNOLOGY LLC

17455 NE 67th Court, Suite 120
Redmond, WA 98052
Phone: +1 425 869 1834
Fax: +1 425 869 5554
E-mail: info@okeanus.com
Website: www.okeanus.com
Contact: Ted Brockett

SOSI and DT Marine brand winches, handling systems, and engineered solutions are now available exclusively from Okeanus Science & Technology. Proven, reliable, and cost-effective standard and custom designed winches range from small all-electric instrumentation winches to high horsepower all-electric or hydraulic umbilical and multi-purpose oceanographic systems. SOSI brand winches can be packaged and supplied with skids, A-frames, over-boarding sheaves, HPUs, and other auxiliary equipment. Okeanus has offices in Houston, TX, Redmond, WA and Houma, LA. Call, email or visit www.okeanus.com for more information.

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When Life and High Reliability Matters

25 Years Heritage in Design and Fabrication - from Space to Deep Ocean Exploration

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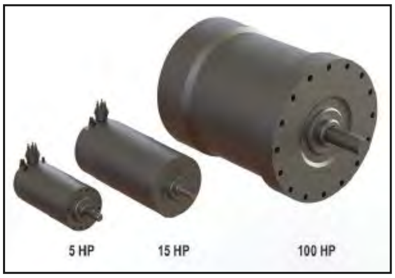

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BATTERY SYSTEMS

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